PB81-231235

Laboratory Studies of Priority Pollutant Treatability

Walk, Haydel and Associates, Inc.
New Orleans, LA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Jul 81

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB81-231235

Laboratory Studies of Priority Pollutant Treatability.

Jul 81

James K. Smith, Robert J. Planchet, E. Jasper Westbrook,
and Frederick J. Zak.

PERFORMER: Walk, Haydel and Associates, Inc., New Orleans,
LA.
Contract EPA-68-03-2579

SPONSOR: Industrial Environmental Research Lab.,
Cincinnati, OH.
EPA-600/281-129
Final rept. Apr 78-Mar 80

This study investigated several methods currently available to reduce the level of pollutants in an industrial plant wastewater stream. Its purpose was to screen these treatment processes. As a result of this screening, further in-depth evaluations should be considered. The study was limited to a detailed evaluation of only five priority pollutants in order to minimize the analytical workload on the project. The five selected for testing the effectiveness of carbon adsorption, resin adsorption, and steam stripping represented compounds occuring at significant levels in the sample. The results of the study indicated high removal efficiency for these five priority pollutants by carbon adsorption and resin adsorption. Although steam stripping reduced chlorobenzene, p-dichlorobenzene and nitrobenzene concentrations by at least fifty percent, it is not effective, under the test conditions, for the priority pollutants phenol or dinitrotoluene. Cost for treatment of streams similar to the stream tested are expected to be high in the order of $2 to $3 per 1000 liters (265, . . .

KEYWORDS: *Water pollution control.

Available from the National Technical Information Service,
Springfield, Va. 22161

PRICE CODE: PC A07/MF A01

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-81-129	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB81 231235
4. TITLE AND SUBTITLE Laboratory Studies of Priority Pollutant Treatability		5. REPORT DATE July 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James K. Smith, Robert J. Planchet, E. Jasper Westbrook, Frederick J. Zak		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Walk, Haydel & Associates, Inc. 600 Carondelet Street New Orleans, Louisiana 70130		10. PROGRAM ELEMENT NO. 1BB610
		11. CONTRACT/GRANT NO. 68-03-2579
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory Office of Research and Development United States Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 4/78 - 3/80
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This study investigated several methods currently available to reduce the level of pollutants in an industrial plant wastewater stream. Its purpose was to screen these treatment processes. As a result of this screening, further in-depth evaluations should be considered.

The study was limited to a detailed evaluation of only five priority pollutants in order to minimize the analytical workload on the project. The five selected for testing the effectiveness of carbon adsorption, resin adsorption, and steam stripping represented compounds occurring at significant levels in the sample. The results of the study indicated high removal efficiencies for these five priority pollutants by carbon adsorption and resin adsorption. Although steam stripping reduced chlorobenzene, p-dichlorobenzene and nitrobenzene concentrations by at least fifty percent, it is not effective, under the test conditions, for the priority pollutants phenol or dinitrotoluene.

Cost for treatment of streams similar to the stream tested are expected to be high in the order of \$2 to \$3 per 1000 liters (265 gallons) for flows of about 1130 liters per minute (300 gallons per minute. Cost effectiveness may favor use of carbon adsorption over resin adsorption. Combination systems are of doubtful value based on the pollutant levels present in the sample stream since they offered no economic advantage over single process operations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release To Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA-600/2-81-129
July 1981
PB81-231235

LABORATORY STUDIES
OF
PRIORITY POLLUTANT TREATABILITY

by
Walk, Haydel & Associates, Inc.
600 Carondelet Street
New Orleans, Louisiana 70130

6-1/2"
9-1/8"

Contract No. 68-03-2579
Directive 2579 WD-6

Project Officers
Kenneth A. Dostal and David R. Watkins
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN. EPA FORM 261)

TYPING GUIDE SHEET

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report discusses treatability screening studies for an industrial wastewater sample containing priority pollutants. Possible process schemes on which to base treatment plant design were evaluated. Results of these screening studies will prove of interest to those evaluating best available technology requirements for removal of priority pollutants. The results will also be helpful for those planning further research including design of a demonstration unit for treating wastes similar to the one studied. The study focuses on carbon adsorption, resin adsorption and steam stripping technologies and develops order-of-magnitude cost relationships for each technology. Various plant sizes and levels of treatment were considered. Combinations of these three technologies were also addressed. IERL-Ci should be contacted for further information on this subject.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ABSTRACT

This study investigated several methods currently available to reduce the level of pollutants in an industrial plant wastewater stream. Its purpose was to screen these treatment processes. As a result of this screening, further in-depth evaluations should be considered.

An actual industrial stream was sampled and this sample used for laboratory bench scale treatment tests. The pollutants present in the waste stream were:

- Chloroform
- Carbon tetrachloride
- Bromodichloromethane
- 1,2-Dichloropropane
- 1,1,2-Trichloroethane
- Benzene
- Nitrobenzene*
- p-Dichlorobenzene*
- Toluene
- Chlorobenzene*
- Ethylbenzene
- Aniline
- Phenol*
- Methylaniline
- N,N-Diphenylhydrazine
- Phthalates
- Dinitrophenol
- Nitrophenol
- Dinitrotoluene*

The study was limited to a detailed evaluation of only five priority pollutants occurring at significant levels in the sample in order to minimize the analytical workload on the project. The five compounds were tested for treatment effectiveness of carbon adsorption, resin adsorption, and steam stripping.

The results of the study indicated high removal efficiency for the five priority pollutants by carbon adsorption and resin adsorption. Total organic carbon (TOC) removal was high for carbon adsorption but somewhat lower for resin adsorption.

Although steam stripping reduced chlorobenzene, p-dichlorobenzene and nitrobenzene concentrations by at least fifty percent, it was not effective, under these test conditions, for the priority pollutants phenol or dinitrotoluene. It was also not effective for TOC removal or for removal of the nonconventional pollutant analine, which was analyzed for during the steam stripping tests.

Costs for treatment of streams similar to the stream tested are expected to be high, in the order of $2 to $3 per 1000 liters (265 gallons) for flows of about 1130 liters per minute (300 gallons per minute). Cost effectiveness may favor use of carbon adsorption over resin adsorption. Combination systems are of doubtful value based on the pollutant levels present in the sample stream since they offer no economic advantage over single process operations.

---

*priority pollutants included in this study

3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

Although available techniques for analysis in the parts per million (ppm) and parts per billion (ppb) range are not precise, the removals indicated and their associated costs are believed to be sufficiently accurate for the screening purpose of this study.

This report is submitted in fulfillment of Contract No. 68-03-2579, Work Directive 2579WD-6 by Walk, Haydel and Associates, Inc. under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period April 15, 1978 to March 16, 1980 and work was completed as of March 16, 1980.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables x
Acknowledgement xi

1. Introduction 1
2. Conclusions 6
3. Recommendations 8
4. Experimental Procedures 9
5. Experimental Results 19
6. Process Design Studies 60
7. Economics 78

References 95
Bibliography 96
Appendix: Laboratory Data 98

Glossary 125

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

FIGURES

Number Page

1. Pilot granular activated carbon columns 13
2. Apparatus used for batch stripping experiments 16
3. Schematic of apparatus for continuous stripping studies . . 17
4. Relationship between ultraviolet absorption and TOC content of the industrial waste stream carbon column effluents . . 21
5. Activated carbon isotherm studies comparing TOC removal by HDC and S-51 activated carbons, pH 9, based on Dohrman Model 54 Analyzer data 23
6. Activated carbon isotherm study to determine effect of pH on reduction of TOC based on Dohrman Model 54 Analyzer data . 24
7. Activated carbon isotherm studies - priority polltant reduction from an industrial waste stream 25
8. Adsorption performance of virgin S-51 carbon 26
9. Carbon adsorption performance with 400°C thermal regeneration - sampling point C 28
10. Comparison of adsorption performance with 400°C and 800°C thermal regeneration - sampling point A 29
11. Carbon adsorption performance with low pressure steam regeneration - sampling point C 31
12. Chlorobenzene breakthrough 34
13. p-Dichlorobenzene breakthrough 35
14. Nitrobenzene breakthrough 36
15. Phenol breakthrough 37
16. Dinitrotoluene breakthrough 38

6-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"

17. Chlorobenzene - carbon exhaustion rate vs. superficial residence time 40

18. p-Dichlorobenzene - carbon exhaustion rate vs. superficial residence time 41

19. Nitrobenzene - carbon exhaustion rate vs. superficial residence time 42

20. Phenol - carbon exhaustion rate vs. superficial residence time . 43

21. Dinitrotoluene - carbon exhaustion rate vs. superficial residence time 44

22. Equilibrium isotherm study using XAD-4 resin based on Dohrman Model 54 Analyzer data 45

23. XAD-4 resin isotherm studies - priority pollutant reduction from an industrial waste stream 46

24. Isotherm studies comparing performance of S-51 activated carbon and XAD-4 resin based on Dohrman Model 54 Analyzer data 48

25. Adsorption column performance of XAD-4 resin with methanol regeneration 49

26. Pollutant breakthrough curves for virgin resin 51

27. Pollutant breakthrough curves after 5 resin regenerations . . 52

28. Resin adsorption capacity 53

29. Process flow - carbon adsorption/regeneration system . . . 63

30. Carbon exhaustion rate vs. superficial residence time - effluent concentration 0.1 ppm 65

31. Carbon exhaustion rate vs. superficial residence time - effluent concentration 1.0 ppm 66

32. Carbon exhaustion rate vs. superficial residence time - effluent concentration 10.0 ppm 67

33. Process flow - resin adsorption/regeneration/solvent system . 71

34. Process flow - steam stripping system 75

35. Capital investment vs. wastewater throughput rate - carbon adsorption 80

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

36. Carbon adsorption treatment cost vs. wastewater throughput rate 81

37. Carbon adsorption treatment cost vs. objective effluent concentration 82

38. Capital investment vs. wastewater throughput rate - resin adsorption 85

39. Resin treatment cost vs. wastewater throughput rate . . . 86

40. Resin treatment cost vs. objective effluent concentration . . 87

41. Resin treatment cost vs. resin life 89

42. Capital investment vs. wastewater throughput rate - steam stripping 91

43. Steam stripping treatment cost vs. wastewater throughput rate 92

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLES

Number		Page
1.	Components Identified by GC/MS Analysis of the Composite Test Effluent	2
2.	Compounds Determined in GC Analysis of the Industrial Effluent	20
3.	Activated Carbon Process Studies (Thermal Regenerations)	30
4.	Activated Carbon Process Studies (Steam Regenerations)	32
5.	Comparison of Activated Carbon Process Studies	33
6.	XAD-4 Performance Through Five Regeneration Cycles	50
7.	Initial Distribution of Pollutants in Batch Distillation Test	54
8.	Process Conditions for Continuous Steam Stripping Studies	56
9.	Distribution of Priority Pollutants in Continuous Steam Stripping Studies	57
10.	Selected Properties of Pollutants Studied	58
11.	Comparative Stripping Material Balances (Experimental and Calculated)	59
12.	Equipment List - Carbon Adsorption	64
13.	Equipment List - Resin Adsorption	72
14.	Steam Stripping Design Material Balance	74
15.	Equipment List - Steam Stripping	76
16.	Treatment Costs for Carbon Adsorption	79
17.	Treatment Costs for Resin Adsorption	84
18.	Treatment Costs for Steam Stripping	90
19.	Treatment Costs for Combined Treatment	94

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ACKNOWLEDGEMENT

The industry supplying the test sample is recognized by the participants in this study effort and by the USEPA Effluent Guidelines Division and Industrial Environmental Research Laboratory for their understanding and very open cooperation.

Special recognition is also accorded Mr. D. R. Watkins, IERL-Ci and Dr. Paul Fahrenthold, EGD, who were of great aid in the establishment of this cooperative atmosphere with the industry.

Mr. Ian Harris of Rohm and Haas and Mr. Lou Bilello of ICI Americas are also acknowledged for their guidance regarding adsorption technology.

6-1/2"

9-1/8"

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

SECTION 1

INTRODUCTION

PURPOSE AND APPROACH

This study was conducted to screen potential treatment systems for removal of priority pollutants contained in an industrial waste effluent. It was performed to provide technical and economic guidance based on a "real world" situation and should serve as a basis for any further efforts directed at obtaining specific design information. The industry chosen was a typical medium sized petro-chemical manufacturing complex, basic in the production of substituted aromatics, including amines and diisocyanates. This industry's waste met EPA's study criteria for: 1) the presence of at least five priority pollutants, 2) a multi-product common usage effluent, 3) a demonstrated toxicity of the waste, and 4) lack of a specific treatment background.

A five drum grab sample used in testing was considered representative for the manufacturing processes involved. Although confidential 308 data necessary for this conclusion was not available to Walk, Haydel & Associates, a review by EPA indicated that the sample was within the expected range for the pollutants identified.

The use of the industrial sample was considered most important. Experimentation with pure organic compounds may fail to predict subtle effects of combinations present in a true industrial waste stream and could invalidate conclusions based on any such laboratory combinations. Based on a review of the industrial sample composition (Table 1), five priority pollutants were selected for study. The following components are considered to be indicative of the priority pollutant characteristics of the stream:

o	Chlorobenzene	8.8	ppm
o	p-Dichlorobenzene	36.0	ppm
o	Nitrobenzene	166.0	ppm
o	Dinitrotoluene	7.9	ppm
o	Phenol	30.8	ppm

The investigative work was limited to only five priority pollutants based on work directive guidance.

Concentrations of the tested priority pollutants and of the non-conventional pollutant, aniline were obtained from gas chromatograph (GC) analyses. Concentrations of other pollutants were determined from gas chromatograph/mass spectrometry (GC/MS) analyses.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 1. COMPONENTS IDENTIFIED BY GC/MS ANALYSIS OF THE COMPOSITE TEST EFFLUENT

Chloroform*
Carbon tetrachloride*
Bromodichloromethane*
1,2-Dichloropropane*
1,1,2-Trichloroethane*
Benzene*
Nitrobenzene*
p-Dichlorobenzene*
Toluene*
Chlorobenzene*
Ethylbenzene*
Aniline
Phenol*
Methyaniline
N,N-Diphenylhydrazine*
Phthalates
Dinitrophenol*
Nitrophenol
Dinitrotoluene*

*priority pollutants

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

An earlier literature search (1) had indicated carbon adsorption, resin adsorption and steam stripping as potential treatment systems for removal of the priority pollutants identified. These technologies were evaluated in the present study for their individual effectiveness and their effectiveness in combination.

The conceptual design used the results of laboratory bench scale tests on the waste stream sample. Order-of-magnitude capital and operating cost estimates were made for specific levels of treatment and for specific waste flow rates.

The screening evaluation objectives were accomplished. The tests and studies demonstrate degrees of removal which can be expected, as well as relative costs for the three treatment methods. Conclusions on the combined technologies are subjective, since actual laboratory test data were confined to single technologies.

A brief review of the applicable technologies and the type of data obtained is presented below. The major sections of this report which follow present conclusions and recommendations for additional effort. Other major sections present technology considerations in more detail as well as a discussion of process, economic and laboratry studies.

APPLICABLE TECHNOLOGIES

Carbon Adsorption

The treatment of industrial wastewater using activated carbon has expanded significantly in recent years. One of the primary reasons for the increasing use of this technology is the development of high hardness carbons, which make their regeneration and reuse more economically attractive (2).

The design of an actual activated carbon industrial wastewater treatment plant, where facilities do not exist, involves the collection and evaluation of laboratory and pilot plant data from which realistic engineering decisions can be made. Since the basis for design would revolve around the performance characteristics of the activated carbon, a thorough evaluation of the adsorbent's properties is essential.

The applicability of a particular carbon is indicated by batch equilibrium (isotherm) evaluations of adsorptive capacity as a function of residual pollutant concentration. Dynamic tests are necessary for design data. These tests develop relationships between the total quantity of liquid treated in a continuous column system and the effluent concentration of the components being adsorbed. The experimental data can be scaled up to develop equipment requirements for plant size operations and costs for the adsorption and regeneration systems.

Fixed or pulsed bed designs are utilized for carbon adsorption, as discussed in Section 6. The carbon usually is more fully saturated in a pulsed bed system and such a system is therefore expected to minimize the amount of carbon handled and the costs of regeneration.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-3/4"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

For the purpose of this study, equilibrium isotherms were developed for two carbons at three pH conditions.

The laboratory evaluation also included thermal and low pressure steam regeneration of carbon spent in the dynamic tests. The adsorption performance of the carbon after thermal (400°C) and low pressure steam (138KPa) regeneration was monitored for a maximum of five cycles. Single run comparisons were also made of carbon adsorption performance after single cycle 400°C and 800°C thermal regeneration.

Resin Adsorption

Aromatic compounds, such as the priority pollutants present in the wastewater selected for this study, are currently removed in certain commercial situations using porous polymeric adsorption resins (3). As with carbon adsorption, an actual design, where equivalent facilities do not exist, requires fundamental laboratory data. Adsorption isotherms are necessary for initial evaluation, and dynamic tests provide design data for cost studies and economic determinations.

Potential advantages of resin adsorption include adsorptive selectivity through resin choice, possible recovery of pollutant materials, low energy consumption, and durability of the resin matrix.

Disadvantages include a usually lower adsorptive capacity than competitive adsorption systems such as activated carbon, the necessity for a solvent recovery system and the relatively high cost of resin.

Dynamic tests are run to establish equipment sizing criteria. Adsorption on polymeric resins is normally carried out in fixed beds of resin beads. Periodic in situ regeneration of such beds is necessary to maintain adsorptive capacity. Thus a minimum of two columns is necessary for continuous wastewater treatment. Series or parallel arrangements may be employed for multiple bed systems.

Based on the guidance provided by the resin supplier and clearcut applicability, evaluation of more than one resin type was not considered necessary. Equilibrium studies were performed with XAD-4 resin at two pH conditions. Scope limitations of this project prevented the very long series of adsorption/regeneration cycles necessary to statistically confirm resin capacity and to indicate an ultimate resin life. Therefore resin was monitored for only five methanol regeneration cycles. Cited commercial applications (3) point to useful resin life exceeding several hundred cycles over a period of years. This is an important economic consideration due to the high cost of resin.

Steam Stripping

Removal of organic priority pollutants from wastewater by steam stripping relies on the combination of volatility and relatively low solubility of each organic pollutant. Many aromatic compounds, such as those present in the subject wastewater, exhibit these properties. The materials which are more difficult to separate require additional separation stages and reflux, with consequent economic penalities. Packed or trayed columns are commonly used in this type of stripping operation.

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

It is generally recognized that the design of stripping systems often can be accomplished without testing because rigorous calculations, based on thermodynamic data, can satisfactorily simulate performance. Bench scale stripping tests are advisable for confirmation or calibration purposes where complex systems are involved.

Equipment sizing and energy and material balances from testing and fundamental calculations provide information necessary for economic evaluations. The economics of steam stripping, as a treatment operation, are particularly sensitive to the amount and cost of steam or other heat sources used for heating the water to be treated and for providing stripping vapor flow.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

SECTION 2

CONCLUSIONS

Both adsorption systems evaluated appear capable of removing the five selected priority pollutants to levels of 0.1 ppm or lower. Carbon adsorption was very effective in TOC removal, which indicates very good removal of the other organic compounds present. Resin adsorption was somewhat less effective in this regard.

Of the two adsorption systems studied, carbon adsorption appears slightly more cost effective. There are no apparent advantages in using these systems in combination with each other. Price and replacement rates of adsorbent are major factors in the estimated economics of the two systems.

There was limited carbon adsorption dynamic test data at and below the breakthrough point. The breakthrough profiles used for design development were selected from those runs exhibiting a minimum amount of data scatter. Carbon isotherm data adds confidence to the conclusion that very low treatment levels are possible. Dynamic tests with longer contact times would be helpful in establishing carbon exhaustion rate curves more accurately.

Total annual cost for either adsorption system is exected to be in the order of \$2 to \$3 per 1,000 liters for flows of about 1,130 liters per minute and for removal down to 1 ppm, at most, for each of the five selected priority pollutants. Prior to round off, the costs for carbon adsorption appear to show a slight advantage. The potential effect of assumptions serving as cost bases is such, however, that differences may not be significant. Unit costs would decrease for either system with increased wastewater throughput and may drop to less than \$2 per 1,000 liters for facilities with very high flow rates. Below the treatment level of 1 ppm, costs are relatively insensitive to the degree of removal.

For a pre-treated waste, or a waste containing less of the contaminant than the test sample, costs for either adsorption process would be expected to drop only moderately.

Steam stripping was not effective at the pH level tested (pH of 9) for the removal of the priority pollutants phenol and dinitrotoluene or the non-conventional pollutant aniline. TOC removal was also relatively low.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

For a steam stripping operation to reduce only some of the priority pollutants present to 1 ppm or lower, total annual cost would be on the order of $2 per 1,000 liters based on 1,130 liters per minute of the tested waste. Treatment to significantly lower the concentration of the remainder of the tested priorty pollutants would increase operating costs significantly.

Based on test conditions, costs for steam stripping in combination with an adsorption treatment is not expected to be as favorable as costs for the adsorption treatment alone. At much higher influent stream concentrations, steam stripping may be effective as a pretreatment but this was not evaluated.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 3

RECOMMENDATIONS

Treatment costs developed by this study should be compared to production volumes of manufactured products to test the effect of the treatment systems on product costs. If the impact of these technologies on ultimate product costs are considered reasonable, based on derived benefits, studies should be made to fix costs more firmly and to provide actual design data. These additional studies should involve a small demonstration facility which may be operated long-term at a manufacturing test site.

For carbon adsorption, some additional dynamic test data should be considered, at and below the breakthrough points and with longer contact times. This would add more confidence to the study results where data were extrapolated or estimations were used.

Although based on assumed use rates of adsorbents, carbon adsorption appears slightly more attractive than resin adsorption. Additional effort is warranted to establish these usage rates more accurately prior to selecting a single treatment demonstration facility. An in-depth survey of users of the specific adsorbents should be considered. Also, long range bench scale adsorption/regeneration of the resin should be considered, based on the wastewater used in this study. Although this would be a long term study, minimal analytical effort would be required.

Additional steam stripping tests, at lower pH levels, should be considered as a means of enhancing phenol removal.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 4

EXPERIMENTAL PROCEDURES

Gulf South Research Institute (GSRI) was selected to perform the laboratory analyses and bench scale tests required for this study. The industrial waste stream effluent sample was supplied to the laboratory in five 55-gallon stainless steel drums. Each drum contained approximately 189 liters (50 gallons) of sample. The quantity needed for the following 24 hour period was withdrawn in equal amounts from each drum, composited, stored in a glass container, and allowed to equilibrate to room temperature.

ANALYTICAL METHODS

The initial qualitative and quantitative data were obtained employing EPA's priority pollutant GC/MS procedures (4). This method uses an internal standard of d_{10}-anthracene, which is coinjected with the sample extract to provide a basis for both relative retention time measurements and semi-quantitative mass spectrometric analysis. The overall GC/MS quantification of priority pollutants has been improved by EPA through the use of multiple deuterated internal standards. However, due to anticipated delays in receiving such standards, as well as for overall economy (since solvent extractions would be needed), the GC/MS procedures were not used for final quantitative analysis.

For routine quantitative analysis during the course of the treatment test, the industrial wastewaters were analyzed using direct aqueous injection, flame ionization detection, and gas chromatography. All results for the five priority pollutants are from assay by the GC procedure.

Gas Chromatography/Mass Spectrometry/Data System

Volatile Organic Analyses:

Volatile organic compounds were analyzed using gas chromatographic/mass spectrometric/data system (GC/MS/DS) techniques. A Hewlett-Packard model 5892 mass spectrometer equipped with a dual electron ionization/chemical ionization source was interfaced with a Hewlett-Packard 5710 gas chromatograph equipped with a Grob type all glass capillary injector. Data acquisition and manipulation were accomplished with a Systems Industries 150 data system. Electron-ionization mass spectra were obtained for each sample. The purge and trap technique (5,6) and standardized mass spectrometer operating conditions were used for each analysis. Specifically, helium was bubbled through a 5 to 25ml water sample contained in an appropriately designed purging chamber. The Tenax resin trap was prepared by sparging the samples for 15 min. Once prepared, the resin trap was connected to the GC/MS injector via a specially constructed L-shaped connector so that the resin trap was parallel to the surface of the

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

instrument. An aluminum heating block was placed around the trap, and the volatile organic compounds were desorbed onto a 2 meter by 2 millimeter inside diameter glass column containing 0.1 percent SP-1000 on 80/100 mesh Carbopack C at 0°C. Desorption time was 10 minutes and temperature was 180°C. Following desorption, the GC oven was programmed from 0 to 180°C, and GC/MS data acquisition was initiated. Rigorous quality control measures were applied for the purge and trap and GC/MS operations.

Semivolatile Organic Compounds:

Semivolatile organic compounds were analyzed using a Hewlett-Packard model 5993A microprocessor controlled mass spectrometer equipped with a dual electron ionization/chemical ionization source. This instrument is interfaced with a Hewlett-Packard model 5840 gas chromatograph equipped with a Grob type all-glass capillary column system. Data acquisition and manipulation were accomplished with a Hewlett-Packard 21 MX-E series computer system.

Typically, 1 to 3 microliter aliquots of samples and standards were injected onto a 30 m x 0.25mm inside diameter (i.d.) WCOT SE-30 glass capillary column. GC/MS operating parameters were varied (i.e., column temperature, mass range, sensitivity) according to the individual sample concentrations, standard solutions, or the types of compounds anticipated in the sample.

GC/MS Quality Assurance/Quality Control (QA/QC) Procedures

To test for contamination, reagent/glassware blanks were extracted (where appropriate) and analyzed by GC/MS in a fashion identical to that used for the collected samples. The GC/MS systems were tuned each day using perfluorotributylamine (PFTBA) in accordance with the manufacturer's specifications. Instrument performance was verified by inspection of the mass spectrum of decafluorotriphenylphosphine (DFTPP), a compound which is sensitive to subtle changes in tuning characteristics. The instrument was tuned to duplicate literature spectra of DFTPP so that spectra generated by the GSRI instruments could be compared with reference spectra produced by other laboratories and spectral libraries.

Gas Chromatography

Gas chromatographic analyses were performed using a Perkin-Elmer model 3920 gas chromatograph equipped with a flame ionization detector (GC/FID). Samples were analyzed using direct aqueous injection (DAI) into a 2 m x 2 mm i.d. glass column packed with 10 percent FFAP on 80/100 mesh Supelcoport. Typical operating conditions were as follows: injector temperature, 150°C; column temperature, 75°C (held for 4 minutes) to 260°C (held for 2 minutes) at 8°C/min: interface temperature, 250°C; carrier gas, nitrogen; flow rate, 40 ml/min; sample size, 1 to 5 microliter aliquots. On each day that samples were analyzed, a standard solution containing the compounds of interest was run as a QA/QC check on GC performance. This procedure established a calibration curve for compound quantification and provided daily checks on sample or system contamination.

Total Organic Carbon Analysis (TOC)

Nonpurgeable total organic carbon (NPTOC) analyses were performed using the Dohrmann Model 54 Analyzer. In accordance with the procedure recommended by the manufacturer, 10 ml of sample was introduced into the instrument, acidified, purged for inorganic carbon, and oxidized using an ultraviolet catalyzed system. The organic carbon was converted to carbon dioxide which was detected and quantified using a flame ionization detector. QA/QC analyses for NPTOC consisted of water blanks, method blanks, spikes, duplicate analyses, and standard solutions with concentrations of 1,000, 2,000, and 3,000 ppb NPTOC.

Ultraviolet Absorption Analyses

This assay was incorporated into the program to provide on-line continuous monitoring of adsorption column effluents. A Beckman DBG spectrophotometer equipped with a 1 cm continuous flow cell was incorporated into the column effluent line. By means of a simple arrangement, the sampling monitor was transferred downstream as 20 percent TOC breakthrough was observed at 230 mm to determine total organic content. Before each test, the response of the on-line system was calibrated with several dilutions of the feed stream. A correlation was established between the ultraviolet absorption and total organic content by comparing a series of duplicate samples.

ACTIVATED CARBON STUDY

Two carbons (Hydrodarco C (HDC) and Darco S-51, both registered trademark items supplied by ICI Americas, Inc.) were selected for evaluation. The HDC was received as a powder and the S-51 was in granular form. The selection of which carbon should be used in dynamic testing was based on the analysis of the equilibrium study results.

Equilibrium Studies

Five priority pollutants (chlorobenzene, p-dichlorobenzene, nitrobenzene, phenol, and 4,6-dinitrotoluene) were selected as compounds of interest to be monitored by the GC method. In addition, the total organic carbon content was obtained to monitor gross organic removal.

The studies were performed in a batch mode by exposing a fixed volume of the test stream to five carbon dosages. A volume of 100 ml of the effluent was mixed with 0.1, 0.5, 1.0, 5.0, and 10.5 grams of activated carbon. Prior to exposure, the carbon had been powdered, washed with distilled water, dried, and screened according to standard laboratory methods (7). The test batches were sealed with Teflon lined caps, placed on a wrist arm shaker, and agitated for 18 hours. After 18 hours, the carbon was allowed to settle, and samples were withdrawn from the aqueous phase and filtered for analysis, which determined TOC content and the concentrations of individual priority pollutants still in solution.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The influence of pH on the adsorption characteristics of the test stream was determined by adjusting the pH of the sample (as received, approximately a pH of 9) with hydrochloric acid to a pH of 7 and a pH of 3 and repeating the experiment.

Dynamic Studies

Three series of continuous flow adsorption runs were performed on S-51 carbon. The initial virgin carbon was regenerated up to five times during each series. These tests were conducted in a three-column train (Figure 1) in order to determine system carbon exhaustion rates as a function of wastewater residence time. The series of runs were performed, employing 400°C thermal regeneration, 800°C thermal regeneration and 120°C steam regeneration. The columns were 2.54 cm i.d. stainless steel pipe, cut into 0.9 m lengths, interconnected with 6 mm stainless steel tubing and valves. The valving arrangement allowed both upflow and downflow in parallel or series operation. Influent flow was adjusted by means of a variable supply pump. A low pressure gauge immediately before column one measured column clogging.

Flow studies were performed with a 0.3 m bed height in each column. The average dry weight of carbon per column was 50.3 grams. Because an investigation of linear velocity as a variable in adsorption performance was beyond the scope of the study, a single flow rate was selected for all tests. Selection was based on the rate expected to be used in a full scale plant. Based on the range indicated in the "Carbon Adsorption Handbook" (8) a mid-point value of 3.7 meters per hour was selected as the rate for use in this study. This velocity was calculated to be equivalent to 27 milliliters per minute in the columns being used.

All tests were performed at room temperature (25°C ± 3°C). The carbon was prewetted prior to each adsorption test by backwashing with distilled water. To assure complete prewetting, a backwashing rate of 160 ml/min or approximate 22 m/hr linear velocity was employed. The prewetting expanded the bed approximately 100 percent.

Thermal Regeneration Procedure:

Five thermal regeneration runs were performed, four at 400°C and one at 800°C. Independent column regenerations were accomplished in situ by draining the columns, establishing a flow of dry nitrogen, raising the temperature to 120°C, and drying overnight. The temperature was controlled with Fisher pyrolytic ovens that fit snugly around the test columns. After drying, the temperature was raised to the regeneration temperature and maintained under nitrogen flow for 1 hour. The column was cooled to room temperature and rewetted with distilled water for the next adsorption run. After rewetting, regeneration was verified by the absence of color in and ultraviolet absorption by the column wash.

Steam Regeneration Procedure:

Five steam regenerations were performed on the three test columns following their conversion to a parallel flow arrangement. The apparatus used for the steam regeneration runs used glass beads instead of glass wool to keep the carbon beds in place, and a filter was added to the influent line. The full series of five

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

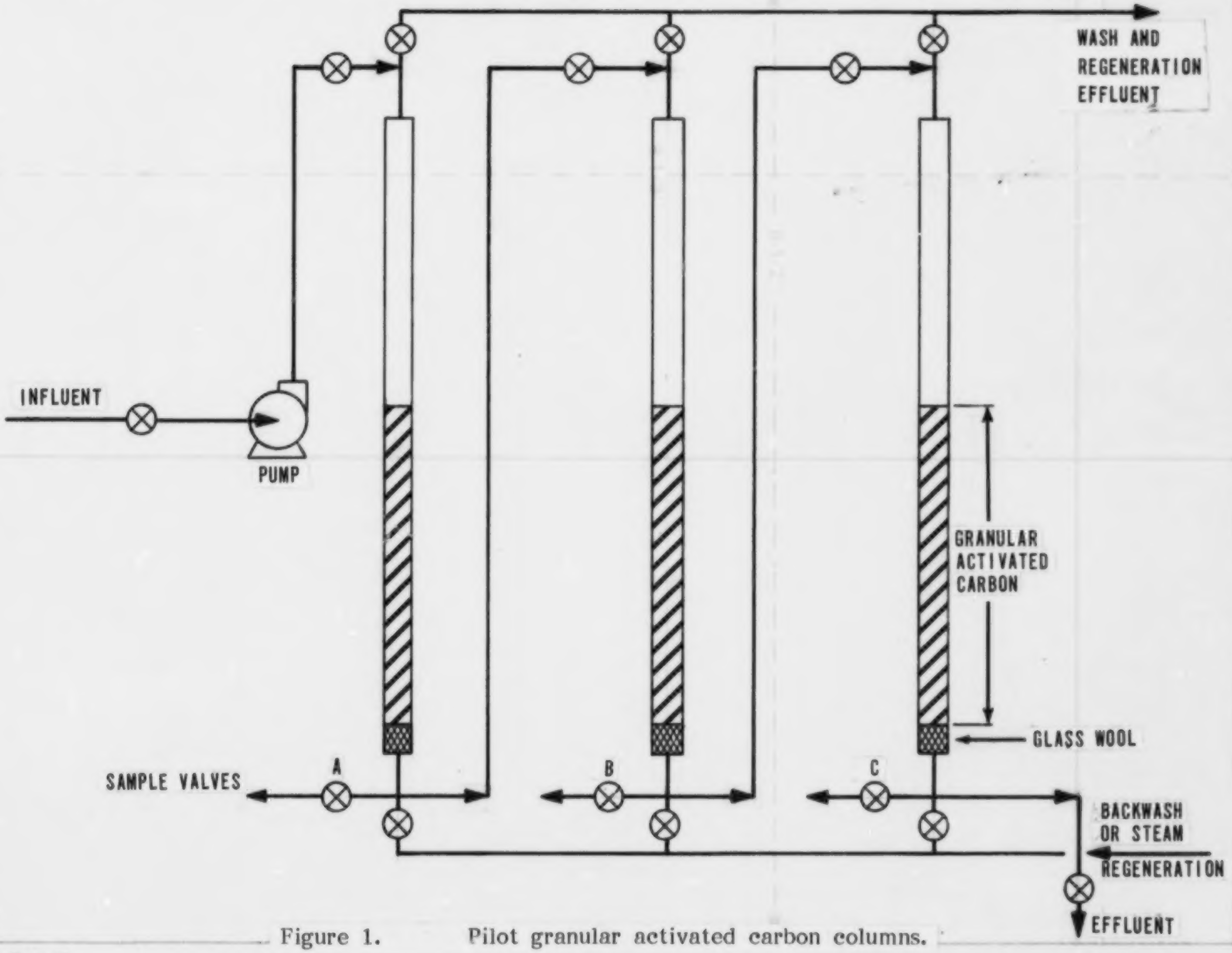
WASH AND REGENERATION EFFLUENT
INFLUENT
PUMP
GRANULAR ACTIVATED CARBON
GLASS WOOL
SAMPLE VALVES
A
B
C
BACKWASH OR STEAM
REGENERATION
EFFLUENT

Figure 1. Pilot granular activated carbon columns.

EPA-287 (Cin.)
(4-76)

regenerations, following each column test, was performed without interruption.

The spent columns were flushed with distilled water until no color was apparent in the effluent. Low pressure steam 117kPa to 138kPa (17 to 20 psi) at the heads of the columns was established and maintained for 5 hours. The column temperature stabilized at approximately 120°C. To avoid condensation and build-up of liquid in the early stages of the regeneration, the steam was run in a forward downflow mode, rather than as a backflush. After regeneration and before the next run, the columns were washed with distilled water. Regeneration was verified by the absence of ultraviolet absorption by the distilled water wash.

XAD-4 ADSORPTION STUDY

In order to analyze resin effectiveness, a registered trademark item, Amberlite XAD-4 manufactured by Rohm & Haas, was selected for evaluation. It is a macroreticular polymeric resin exhibiting hydrophobic and low ionic activity, characteristics applicable to removal of organic compounds from an aqueous solution. The pore size of the resin selected allows for smaller molecules such as single ring aromatics to migrate easily to active surface points. Substantially larger molecules are excluded. Alternate resins from the same manufacturer are primarily applicable to services requiring their larger, less selective pore sizes.

Equilibrium Studies

Prior to dynamic testing, an equilibrium isotherm study was performed in a batch mode by adding various resin loadings (0.2, 0.5, 1.0, 5.0, and 10.0 grams) to 100 ml of a composite of the test stream. Two pH conditions (a pH of 9 and a pH of 6) were evaluated. The lower pH was obtained by adjustment with concentrated HCl. The samples were equilibrated at room temperature over 72 hours on a wrist arm shaker. After equilibration, the samples were allowed to settle and were analyzed for the five priority pollutants and TOC.

Dynamic Studies

Six runs, with methanol regeneration between runs were performed to establish equipment sizing criteria. Initial column preparation and column regenerations were accomplished by the procedures recommended by Rohm & Haas (9). A single column, 0.9 m long and 2.54 cm i.d., was filled with an XAD-4 resin slurry. The total bed height was 45 cm, with a bed volume of 195 cubic centimeters.

The experiment was performed at room temperature and a flow rate of four bed volumes per hour (13.0 ml/min). The column effluent was continuously monitored for organic breakthrough using ultraviolet absorption. Time history related samples were collected and analyzed for TOC and the five priority pollutants.

Regeneration

The relatively weak van der Waals' binding forces which stabilize the resin adsorption are easily overcome by a solvent system which permits removal of the adsorbed pollutants and regeneration of the resin. Commonly used solvents include

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

methanol, acetone, and isopropanol. Methanol was selected for the experimental test and for the evaluation design basis, because of its cost and ease of separation by distillation from water and dissolved organics.

Column preparation prior to all runs with regenerated resin included backflushing with 8 liters of distilled water, allowing the bed to settle, and treating the resin with five bed volumes (975 ml) of methanol at a flow rate of two bed volumes per hour (6.5 ml/min). This treatment was followed with a distilled water rinse and another methanol flush of two bed volumes at the same 6.5 ml/min flow rate. At the conclusion of the methanol regeneration, the column was backflushed with 2 liters of distilled water, allowed to settle, and rinsed with another 2 liters of distilled water to set the bed. The effluent from the final rinse was monitored by examining color and ultraviolet adsorption, to verify regeneration.

STEAM STRIPPING STUDY

The feasibility of stripping organic priority pollutants was investigated by running batch and continuously operated bench scale tests. The activity coefficients of some components, e.g. phenol, may be affected by pH. Optimizing pH for improved stripping performance was not investigated in this study, but should be considered for future testing.

Procedures used in this evaluation involved a single batch stripping experiment with the apparatus shown in Figure 2. Four liters of a composited effluent was added to a 6 liter pot. The pot temperature was raised to boiling with an electric heating mantle. Uniformity of the pot sample was maintained with magnetic stirring. The volatile organic components were stripped in a 61 cm x 7 cm i.d. glass column packed with 1.5 cm diameter polypropylene Raschig rings. The temperature was monitored in the pot and at the top of the column. The stripping products were directed through a chilled condenser to a separation tube. The top of the tube was fitted with a plug of glass wool to break emulsions. The middle of the tube was equipped with a return arm to the top of the stripping column. Sampling points were available to sample the pot, the organic condensate from the bottom of the separator tube, and the acqueous condensate as it was recycled to the top of the stripping column. The batch study was operated as a closed system. All condensate was returned to the top of the stripping column until a constant temperature at the entrance to the condensor indicated column stabilization. The distillate was then fed through the condensor to the separation tubes to recover the organic phase and to recycle the aqueous phase.

A continuous stripping study was conducted by using the batch equipment with the additions shown in Figure 3. The composite wastewater sample was supplied to the stripping column by a variable-speed micropump. Prior to entering the top of the column, the sample was filtered and preheated between 65 and 75°C, and the flow rate was monitored. The priority pollutants were stripped from the feed solution as it flowed through the packed column. Steam for the stripping was supplied from approximately 4 liters of the column bottom solution, which was maintained at a constant boil. The volume in the reboiler was maintained by withdrawing a volume equivalent to the supply through a heat exchanger,

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

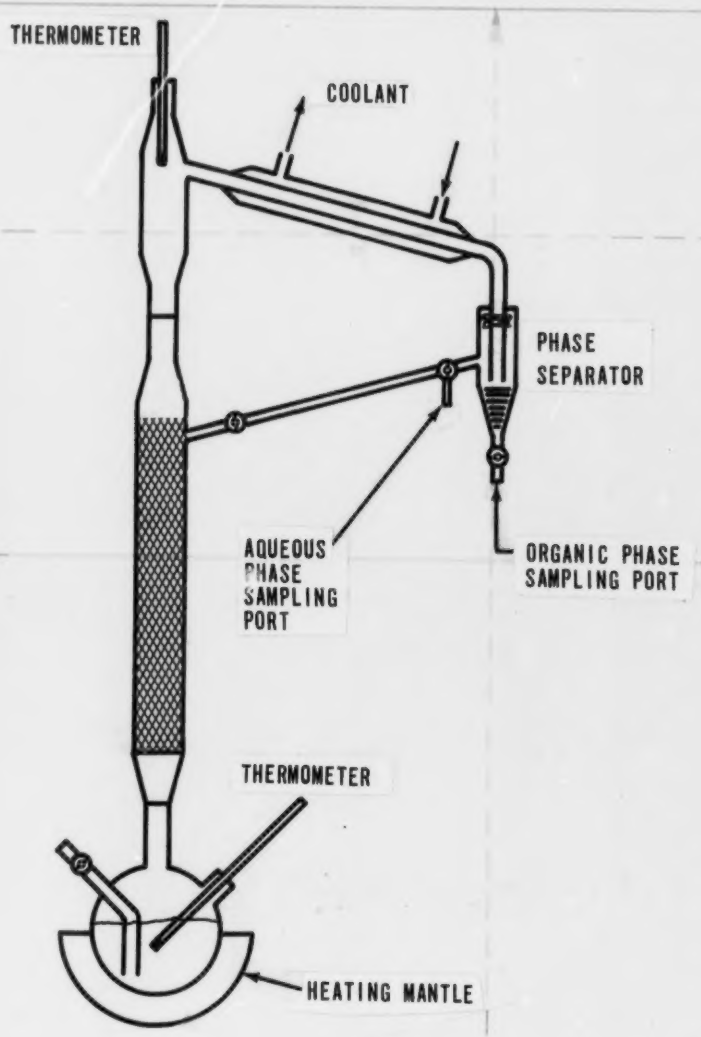
THERMOMETER
COOLANT
PHASE SEPARATOR
ORGANIC PHASE SAMPLING PORT
AQUEOUS PHASE SAMPLING PORT
THERMOMETER
HEATING MANTLE

Figure 2. Apparatus used for batch stripping experiments.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"

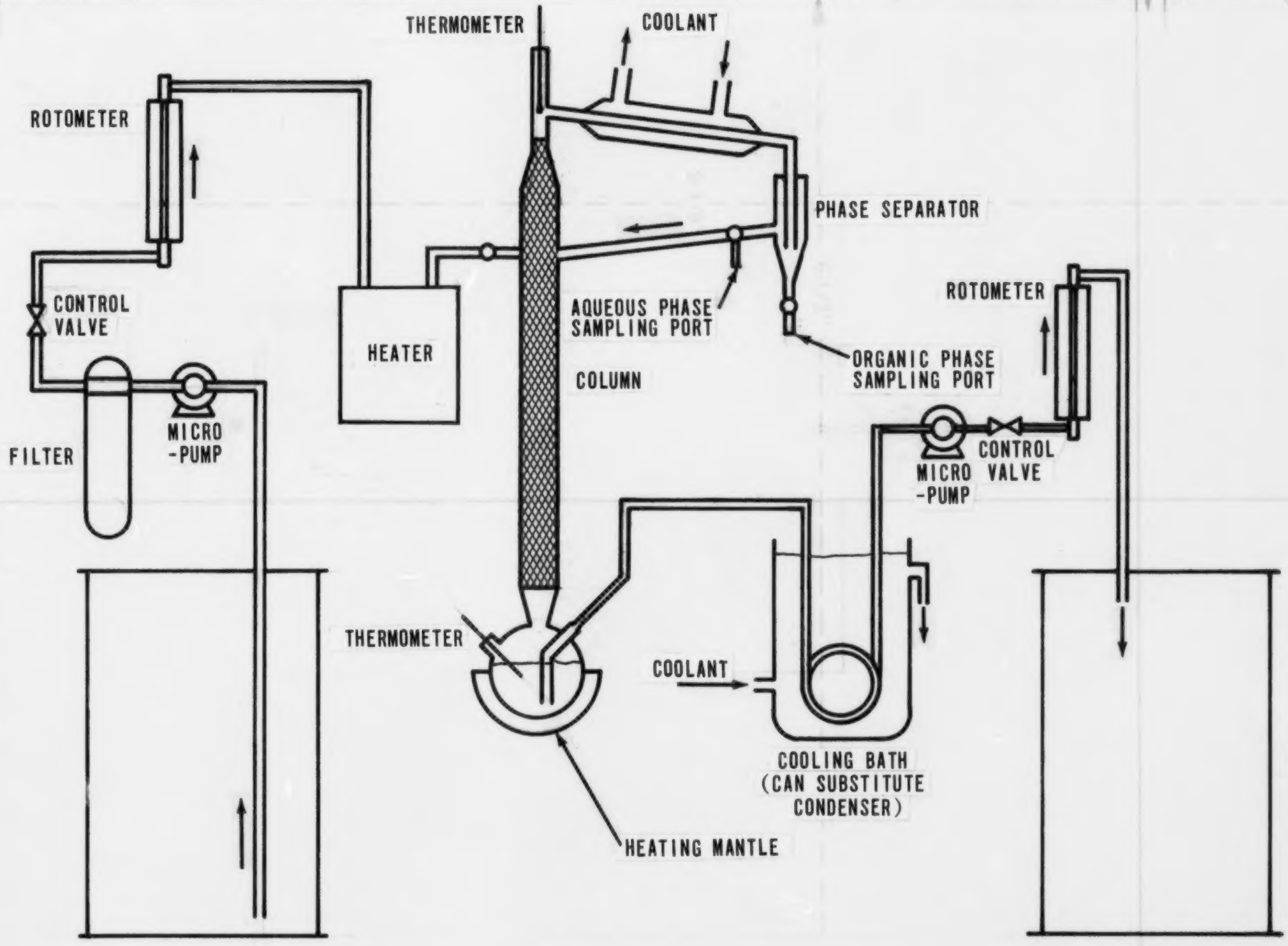
THERMOMETER
COOLANT
ROTOMETER
PHASE SEPARATOR
ROTOMETER
CONTROL VALVE
HEATER
AQUEOUS PHASE SAMPLING PORT
COLUMN
ORGANIC PHASE SAMPLING PORT
FILTER
MICRO -PUMP
MICRO -PUMP
CONTROL VALVE
THERMOMETER
COOLANT
COOLING BATH (CAN SUBSTITUTE CONDENSER)
HEATING MANTLE

Figure 3. Schematic of apparatus for continuous stripping studies.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

using a variable speed micropump. The stripped effluent volume was monitored with a rotameter and collected in a 55-gallon drum. The overhead organic phase was directed through a chilled condensor or to a separation tube.

Two reflux-to-feed ratios were studied. Two higher feed rate runs were set just below the rate at which cooling of the vapor upflow by the feed prevented vapor flow into the condenser. Without vapor entering the condenser, all reflux was inside the column and no condensate was available for phase decantation, the ultimate mechanism for removal of organics. The second feed rate was approximately 60 percent of the first. For each reflux rate, samples of the feed, reboiler or column bottoms, organic phase of the distillate, and the aqueous distillate or reflux phase were collected and analyzed for the five priority pollutants.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 5

EXPERIMENTAL RESULTS

ANALYSIS OF THE INDUSTRIAL WASTE STREAM

Analysis of the industrial waste stream samples indicated that the effuent as received was at approximately a pH of 9. The sample was strongly colored, and little or no precipitate was evident at storage conditions of 4°C. Qualitative analysis by GC/MS provided a positive identification of the presence of compounds listed in Table 1 at concentrations greater than 1 ppb. The adsorption was pH sensitive, as would be expected with phenol and aniline present.

Based on the qualitative analysis, five priority pollutants (chlorobenzene, p-dichlorobenzene, nitrobenzene, dinitrotoluene, and phenol) were selected as marker contaminants to monitor in the test program. Quantitative analysis of the effluent over the duration of the project by GC confirmed minimal changes in composition (Table 2).

The presence of large concentrations of aromatic constituents and the accompanying ultraviolet absorption provided a response for an on-line monitoring of column performance. This response is a measure of the total organic carbon content of the effluent as shown in Figure 4. The ultraviolet instrument response was calibrated based on the untreated TOC concentration in the test stream prior to each run.

ACTIVATED CARBON STUDIES

Equilibrium Studies

The equilibrium adsorption relationship represented by the Freundlich isotherm model were developed:

$$X/M = KC^{1/n}$$

where; X = weight of adsorbed impurities, milligrams
M = weight of activated carbon, grams
C = concentration of impurity remaining in solution, mg/l
K,n = constants

The data from each isotherm were evaluated from a log-log plot of X/M (mg of material adsorbed/g carbon) versus equilibrated solution concentration, C (mg/l). If the majority of organic impurities are amenable to sorption, the resulting plots yield straight lines with slopes of 1/n (based on log values of X/M and C) and an intercept of K (X/M values at C=1 ppm). The constants K and n

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 2.
COMPOUNDS DETERMINED IN GC ANALYSIS OF THE INDUSTRIAL EFFLUENT (ppm)

Date	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Dinitrotoluene	Phenol	Aniline
7-18-79	7.2	35.0	182.9	10.4	30.0	1,197
9-6-79	9.4	35.0	178.0	9.9	30.7	1,143
9-13-79	7.7	37.4	163.6	10.4	32.2	1,605
9-21-79	6.6	37.8	181.3	8.0	31.8	1,329
10-3-79	9.1	37.4	169.0	6.1	33.8	1,635
10-25-79	8.7	38.2	146.0	8.5	29.2	1,083
11-8-79	8.1	35.4	146.2	6.3	29.6	1,466
11-30-79	5.7	34.4	176.0	7.5	27.8	1,272
12-4-79	6.8	36.2	173.0	9.9	29.6	1,258
12-19-79	10.2	37.0	146.0	7.0	34.2	1,302
Average	8.8	36.0	166.0	7.9	30.8	1,329

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

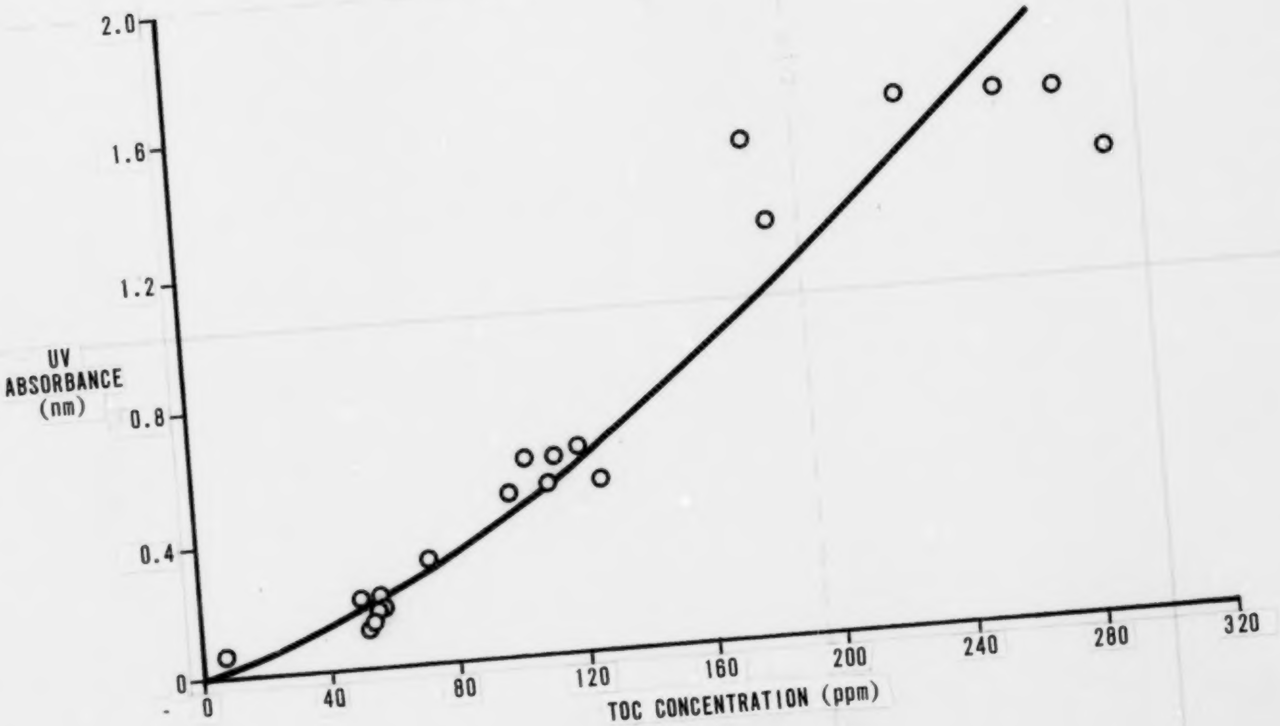

Figure 4. Relationship between ultraviolet absorption and TOC content of the industrial waste stream carbon column effluents.

from the equilibrium relationship that is established between the industrial effluent and the carbon indicates the adsorbability of the organic constituents in the sample. For example, high K and low n values (steep slope) indicate high adsorption throughout the concentration range studied. Low K and high n indicate poor adsorption over the entire effluent concentration range, while a low n and high K indicates good adsorption at high solute concentrations with decreasing adsorption as the concentration is reduced. In ideal systems the quantity of contaminant remaining in solution decreases as carbon dosage is increased. Real systems stop responding to increased carbon dosage as a limiting level of contaminant concentration is reached.

The results of the HDC and S-51 carbon tests are reported in Tables 1A, 2A and 3A of the Appendix. The isotherms for TOC removal at a pH of 9 were developed based on regression analysis and are shown in Figure 5. The S-51 carbon exhibits a better adsorption of TOC components and a smaller concentration dependence, as indicated by the higher intercept and lower slope. Based on these results, S-51 was recommended for dynamic studies, since it displayed a somewhat larger capacity and less concentration dependence.

The adsorptions of TOC from the sample by the S-51 carbon at a pH of 9, 7 and 3 are illustrated in Figure 6. An increased capacity with a decreasing concentration dependence is observed as the pH is lowered from 9 to 3. Adjustment of the waste stream pH from 9 to 3 required 0.208 grams of HCl per liter of waste stream. Since pH adjustment provided only a marginal increase in carbon capacity, dynamic tests were performed without pH adjustment.

The priority pollutant isotherms using S-51 carbon at a pH of 9 are shown in Figure 7. Some obvservations can be made that may be useful in understanding process performance. For example, the nonlinearity of the dinitrotoluene data at low concentrations indicates poor adsorption and a potential leakage of this pollutant in the process studies. The other four priority pollutants should follow normal column breakthrough performance. The data indicate that carbon capacity is lowest for phenol and highest for either nitrobenzene or dichlorobenzene depending on the concentration range considered. The data for dichlorobenzene indicate a stronger concentration dependence in comparison to the other three.

Pilot Studies

TOC removal by virgin carbon (based on ultraviolet absorption) is shown in Figure 8 for the series of three pilot studies. Typical breakthrough profiles were obtained at the sampling points at the exit of each of the three columns. Doubling the total carbon column capacity increased the adsorption capacity of the system more than two fold. A significant but somewhat smaller increase was observed with addition of the third column.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

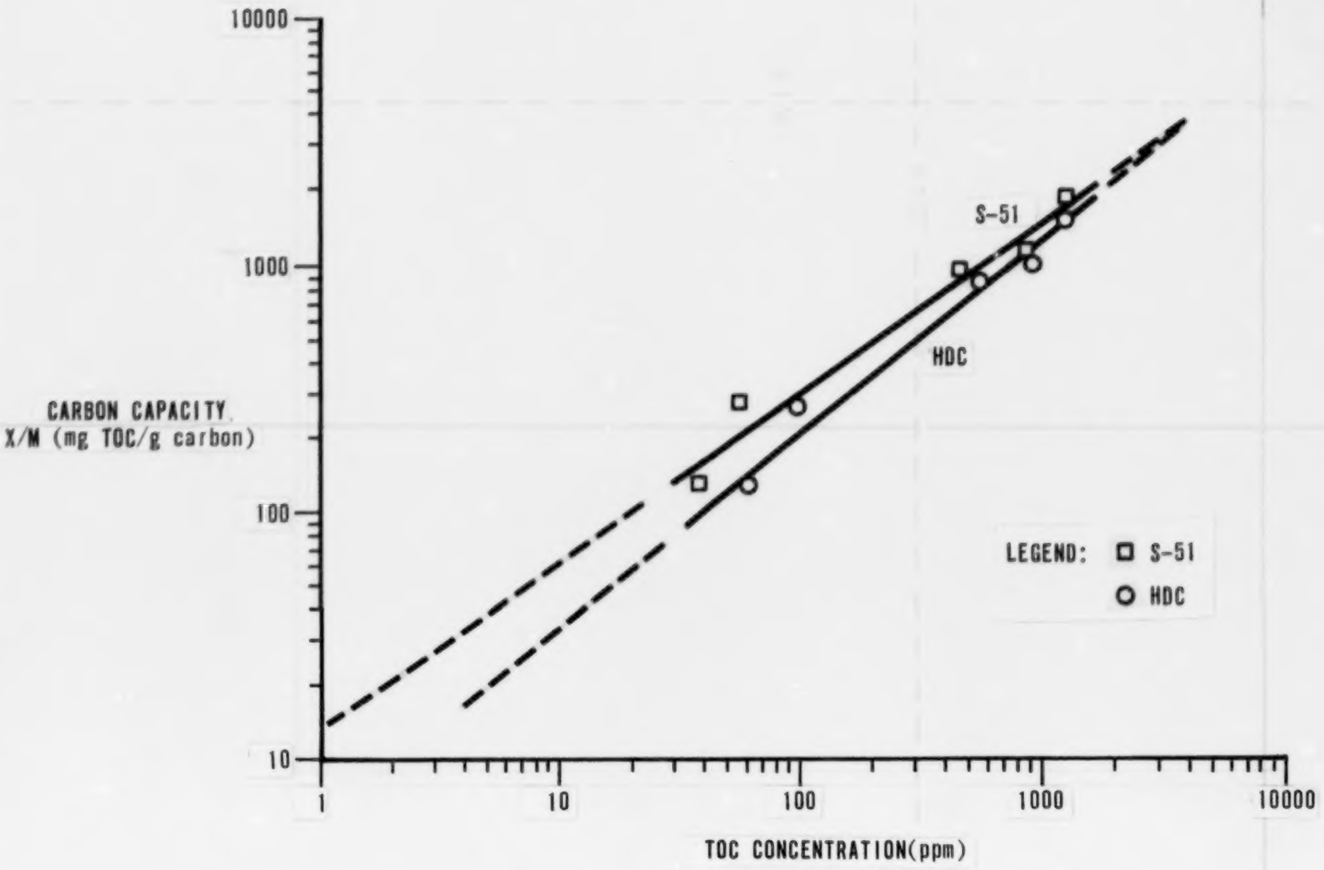

Figure 5. Activated carbon isotherm studies comparing TOC removal by HDC and S-51 activated carbons, pH 9, based on Dohrman Model 54 Analyzer data.

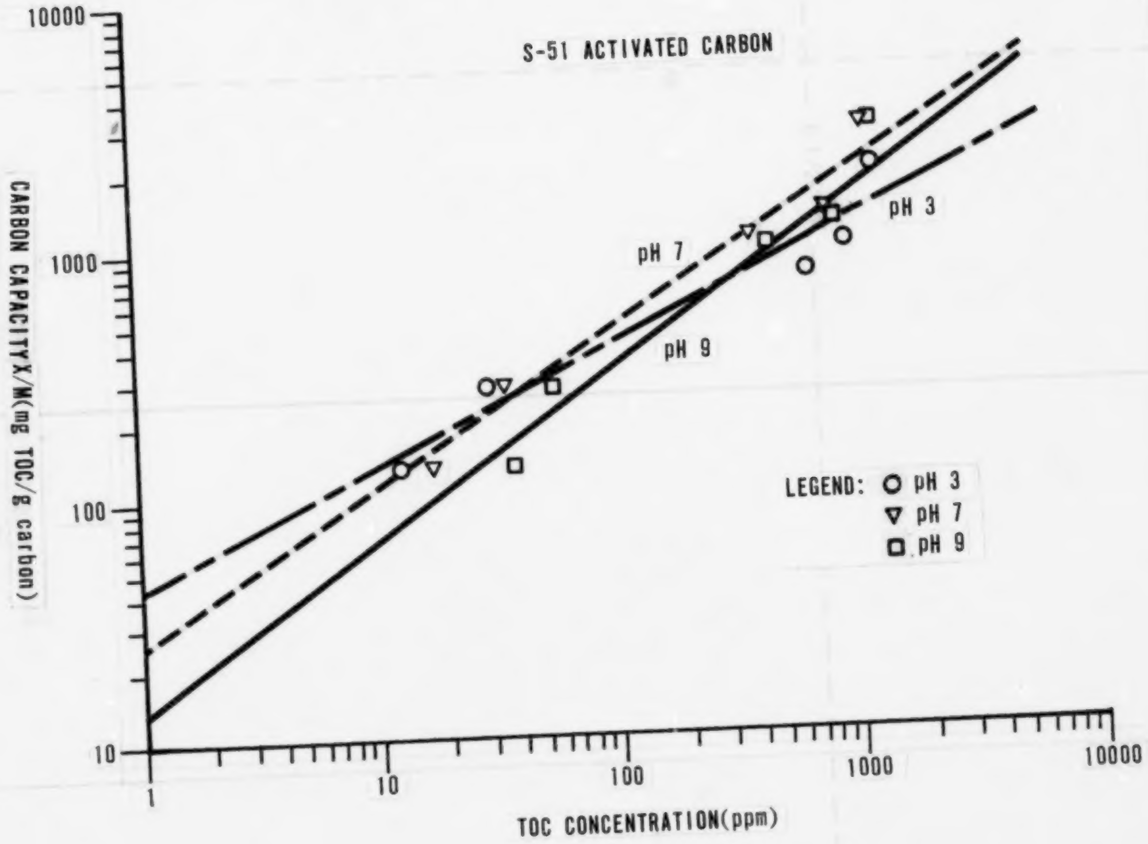

Figure 6. Activated carbon isotherm study to determine effect of pH on reduction of TOC based on Dohrman Model 54 Analyzer data.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287
(4-76)

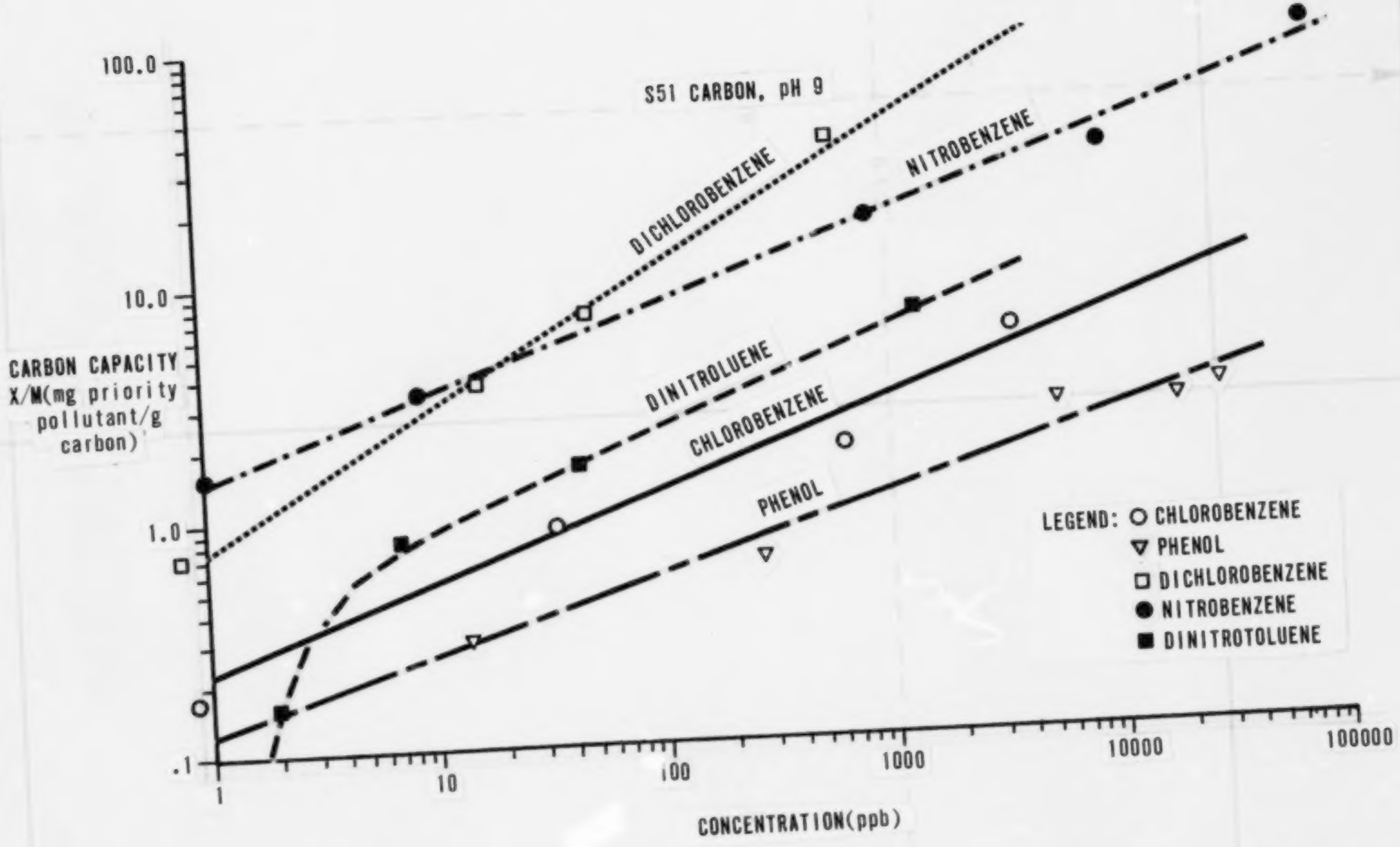

Figure 7. Activated carbon isotherm studies - priority pollutant reduction from an industrial waste stream.

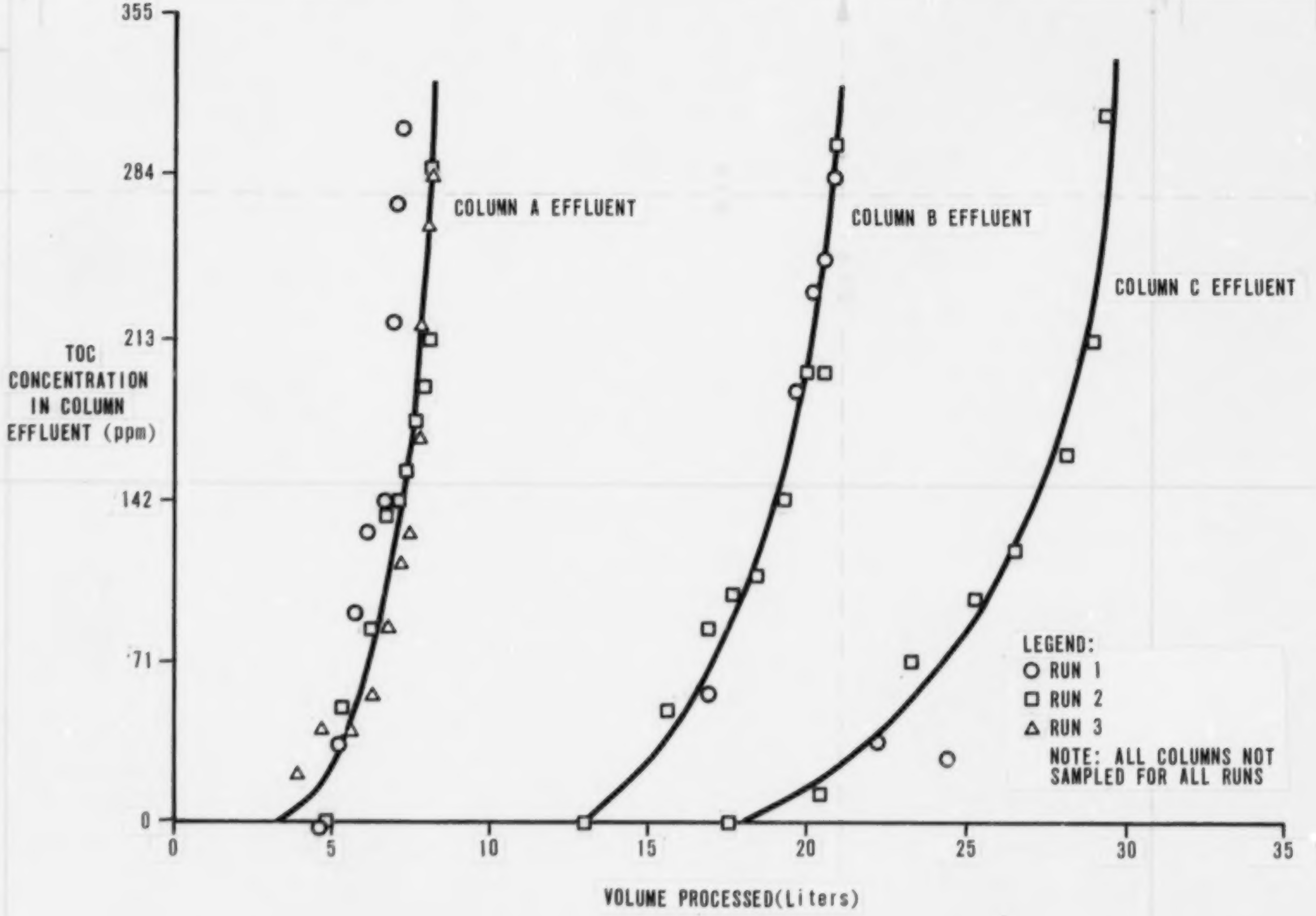

Figure 8. Adsorption performance of virgin S-51 carbon.

Thermal Regeneration

The results of the first series of dynamic studies (initiated with virgin carbon followed by four regenerations at 400°C) are reported in Tables 4A through 8A of the Appendix. The breakthrough performance is depicted in Figure 9 for this series. Based on the volume processed before a 20 percent (284 ppm) breakthrough of TOC, a reduction of capacity of approximately 56 percent was observed after the initial loading and thermal regeneration, with only 35 percent of the original capacity recovered after the fourth regeneration. Since the selection of 400°C as the thermal regeneration temperature was based on the relatively low boiling points of the majority of the priority pollutants in the waste stream, the loss in capacity was larger than expected. The second series of runs (virgin carbon followed by a 800°C regeneration cycle) demonstrated that greater capacity can be maintained through higher regeneration temperatures. The time history data are reported in Tables 9A and 10A in the Appendix.

A comparison of the results of the 400° and 800° trials is shown in Figure 10 and Table 3. The carbon regenerated at 800° achieves 59 percent of the adsorption of the corresponding virgin carbon. The 400° carbon only achieves 21 percent of the original adsorptivity.

Steam Regeneration

The results of the last series of dynamic studies (initiated with virgin carbon, followed by five runs after steam regenerations at 120°C) are reported in Tables 11A through 16A in the Appendix. The breakthrough profile for the total organic content is illustrated in Figure 11. These data and analysis of the performance of the carbon at 20 percent (284 ppm) TOC breakthrough (Table 4) indicate a 45 percent loss at column C after the first regeneration. The performance after subsequent regenerations is similar to the thermal regeneration results, with only 28 percent recovery observed after the fifth regeneration.

The adsorption profile of priority pollutants after steam regeneration is similar to those observed after thermal regeneration, with dichlorobenzene breaking through early.

The three modes of regeneration after one regeneration cycle at sampling point A are compared in Table 5. The best performance of regenerated carbon was obtained after an 800°C thermal treatment.

Breakthrough Curves of Priority Pollutants

Breakthrough curves based on the dynamic test data depict the relationship between the volume of liquid treated in the column and the quantity of each priority pollutant of interest. Breakthrough curves were developed based on a review of all of the test data. The data which correlated best was chosen as representative for design studies and are presented in Figures 12 through 16.

EPA-287 (Cin.)
(4-76)

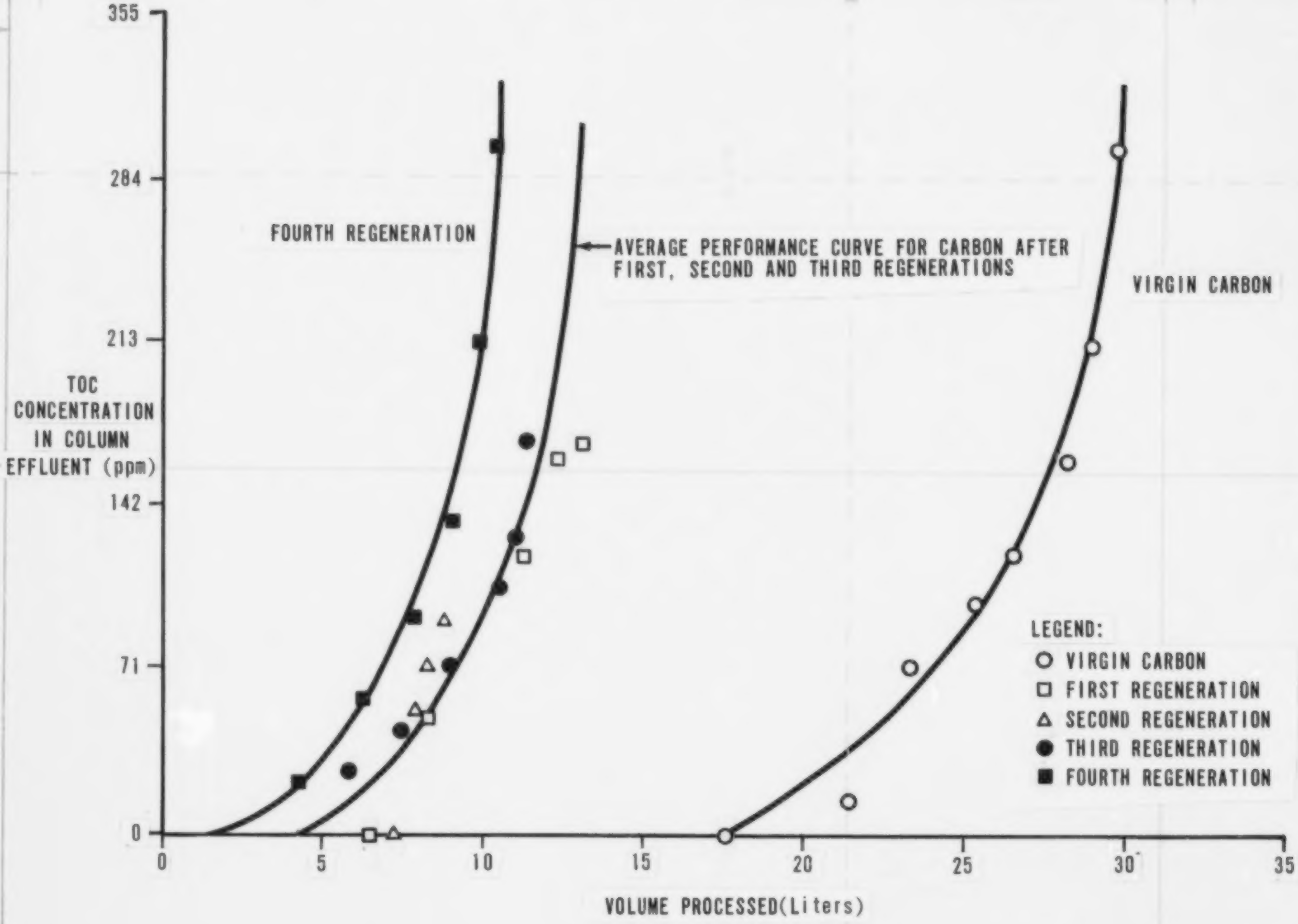

Figure 9. Carbon adsorption performance with 400°C thermal regeneration - sampling point C.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

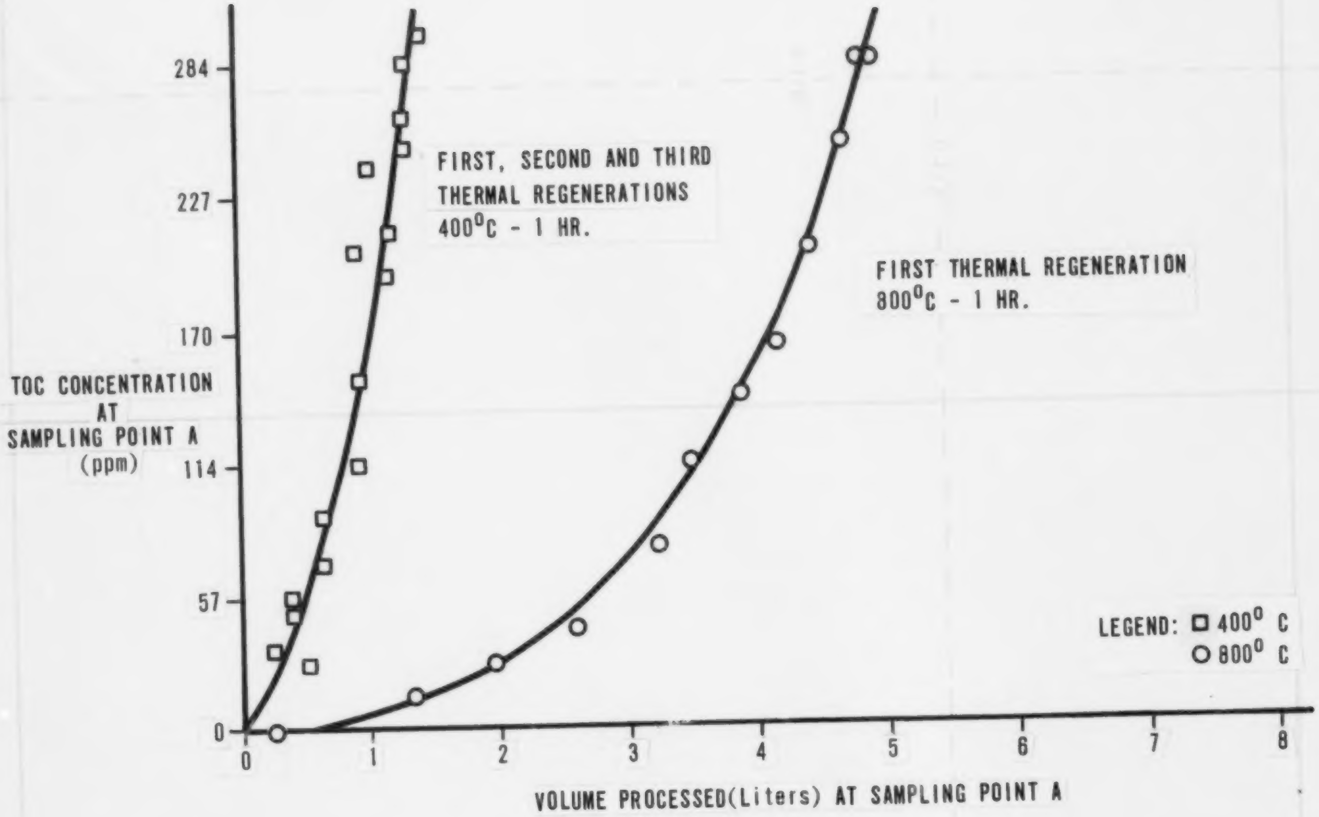

Figure 10. Comparison of adsorption performance with 400°C and 800°C thermal regeneration - sampling point A.

TABLE 3.
ACTIVATED CARBON PROCESS STUDIES (THERMAL REGENERATIONS)

PERFORMANCE AT 20 PERCENT BREAKTHROUGH OF FEED WASTE STREAMS TOTAL ORGANIC CONTENT

Run	Sampling Point	Volume Processed (liters)	Percentage of Virgin Carbon Volume Processed
Virgin Carbon (400° regeneration series)	A	6.2	-
	C	29.5	-
400° Thermal Regeneration			
First Regeneration	A	1.3	21.1
First Regeneration	C	13.0	44.1
Second and Third Regenerations	C	12.4	42.0
Fourth Regeneration	C	10.2	34.6
Virgin Carbon (800° regeneration series)	A	8.2	-
800° Thermal Regeneration			
First Regeneration	A	4.8	58.7

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

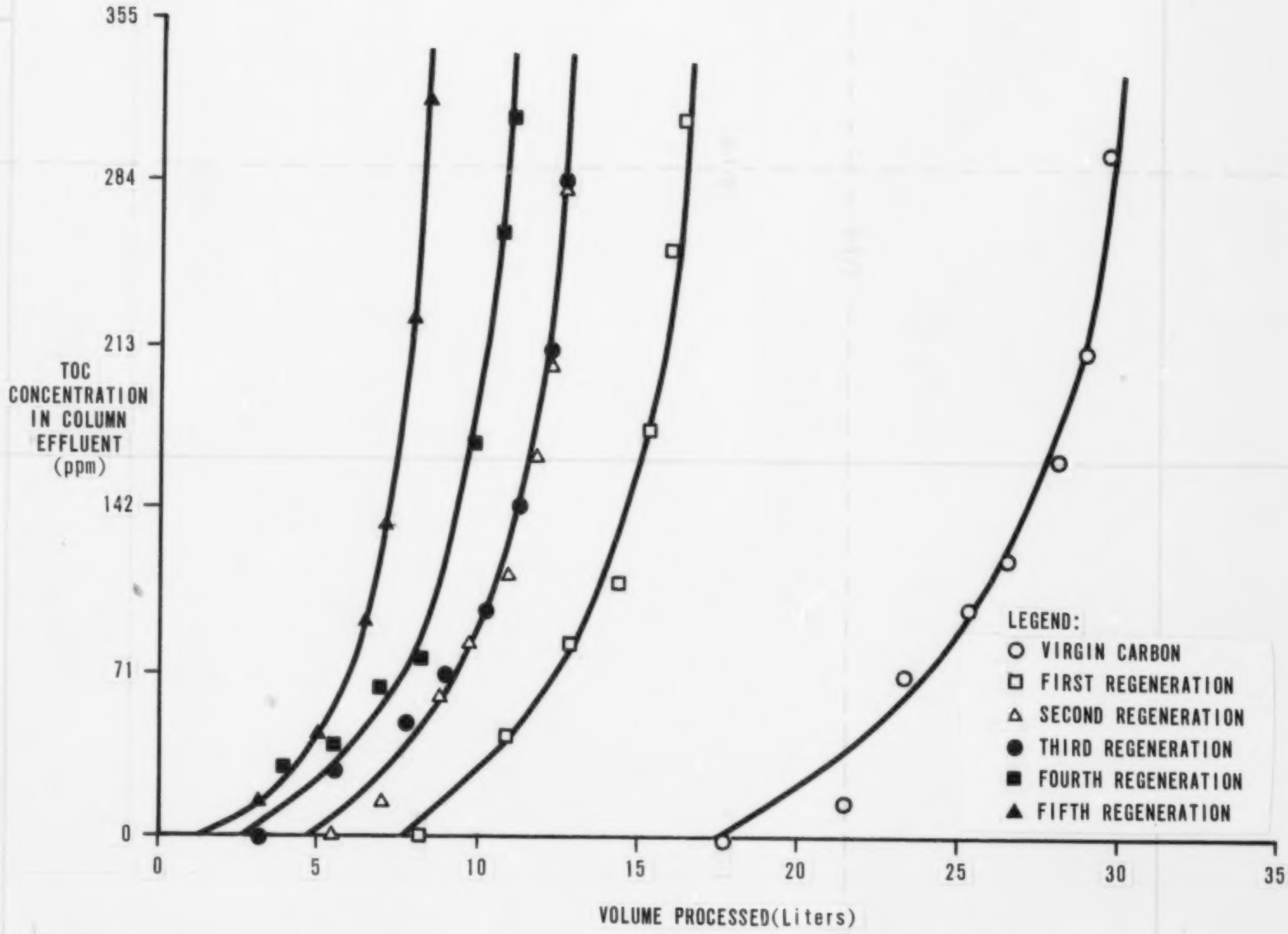

Figure 11. Carbon adsorption performance with low pressure steam regeneration - sampling point C.

TABLE 4.
ACTIVATED CARBON PROCESS STUDIES (STEAM REGENERATIONS)

PERFORMANCE AT 20 PERCENT (284ppm) BREAKTHROUGH OF FEED WASTE STREAMS-TOTAL ORGANIC CONTENT AT SAMPLING POINT C

Run	Volume Processed (liters)	Percentage of Virgin Carbon Volume Processed
Virgin Carbon	29.5	100.0
Steam Regeneration		
First Regeneration	16.3	55.3
Second and Third Regeneration	12.5	42.4
Fourth Regeneration	10.7	36.2
Fifth Regeneration	8.2	27.8

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 5
COMPARISON OF ACTIVATED CARBON PROCESS STUDIES

PERFORMANCE AT 20 PERCENT (284ppm) BREAKTHROUGH OF FEED WASTE STREAMS TOTAL ORGANIC CONTENT AT SAMPLING POINT A

Run	Volume Processed (liters)	Percentage of Virgin Carbon Volume Processed
400° Thermal Regeneration First Regeneration	1.3	21.1
800° Thermal Regeneration First Regeneration	4.8	58.7
Steam Regeneration 120°C First Regeneration	2.4	29.3

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

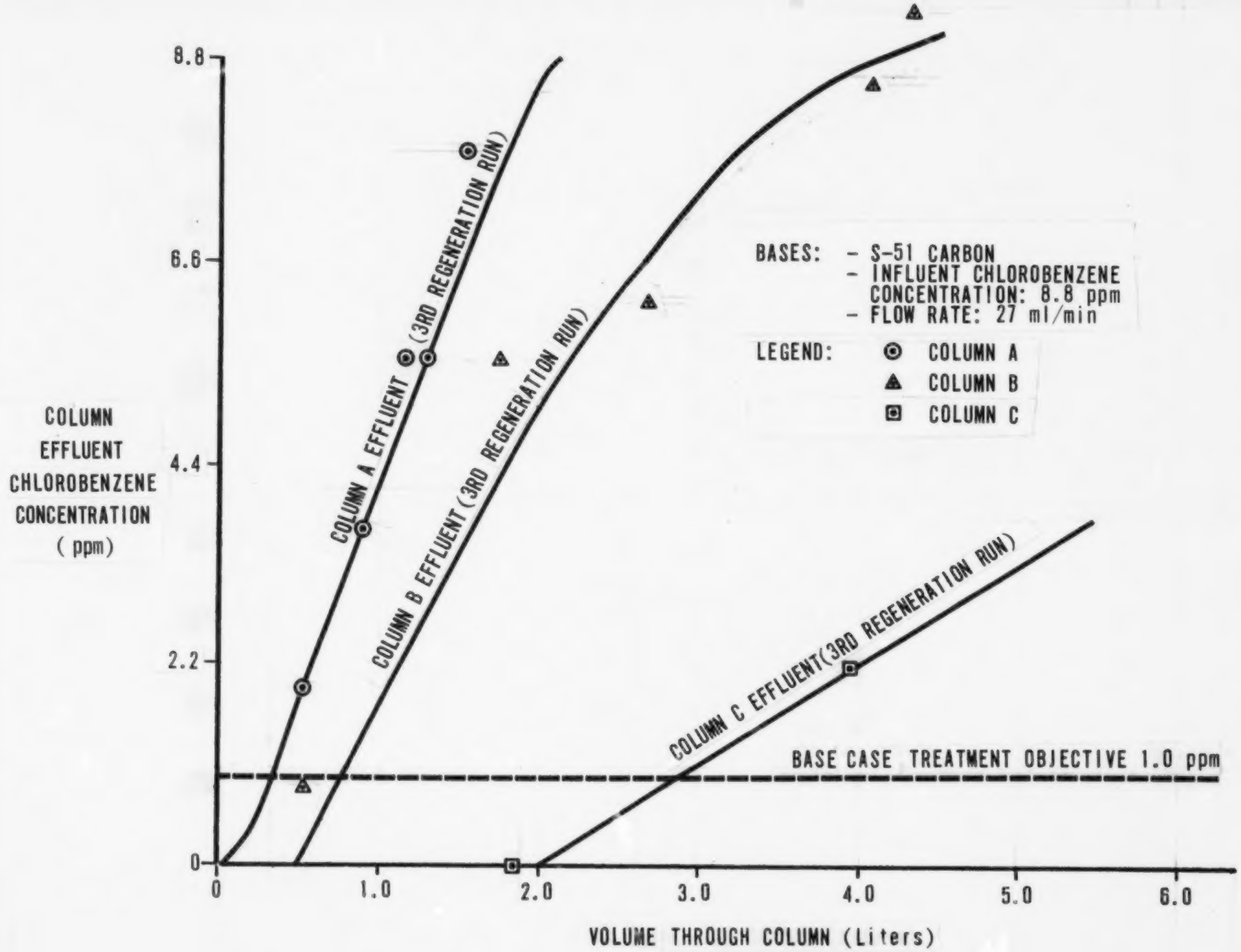

Figure 12. Chlorobenzene breakthrough.

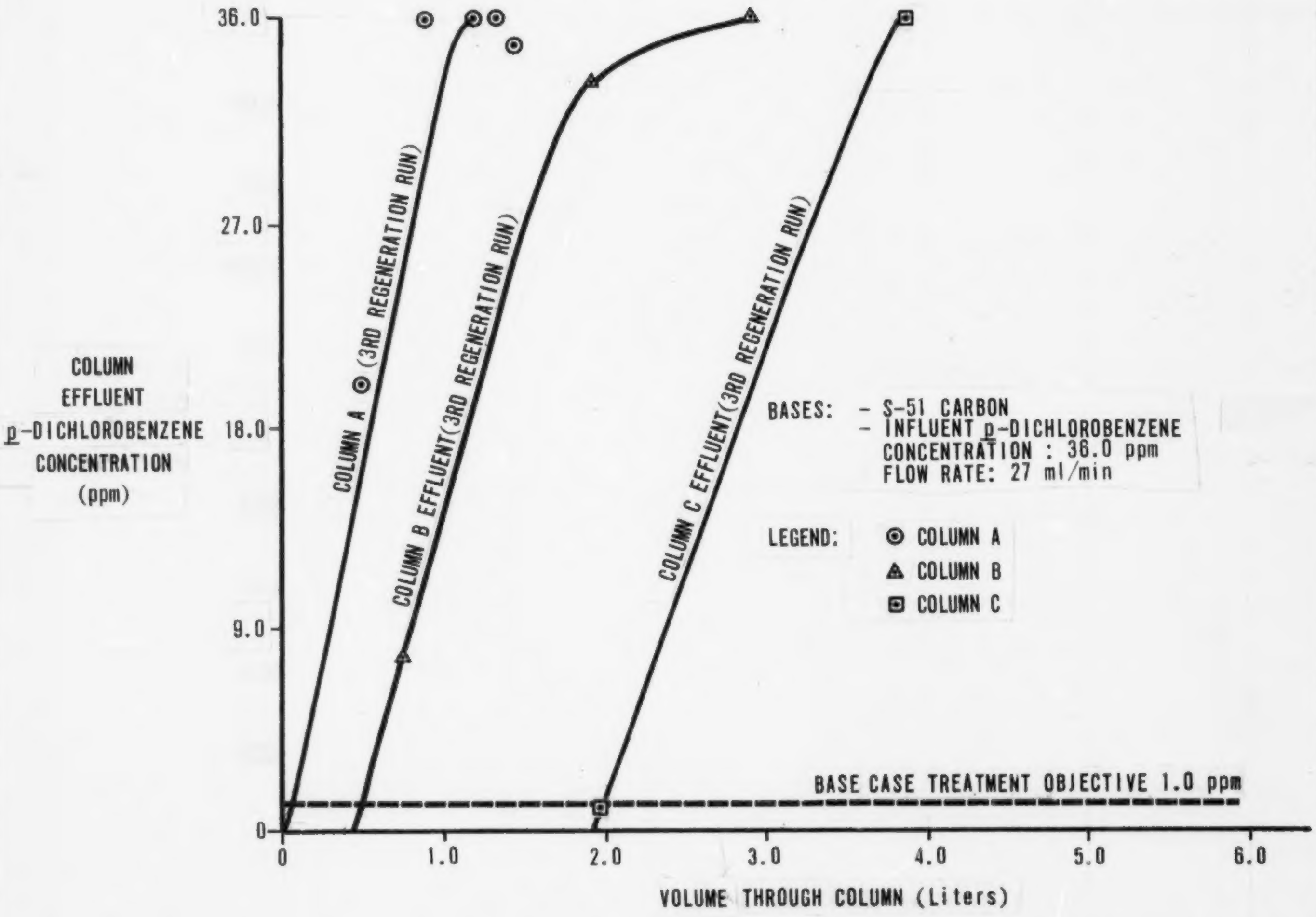

Figure 13. p-Dichlorobenzene breakthrough.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/6
PAGE NUMBER
EPA-287 (Cin)
(4-76)

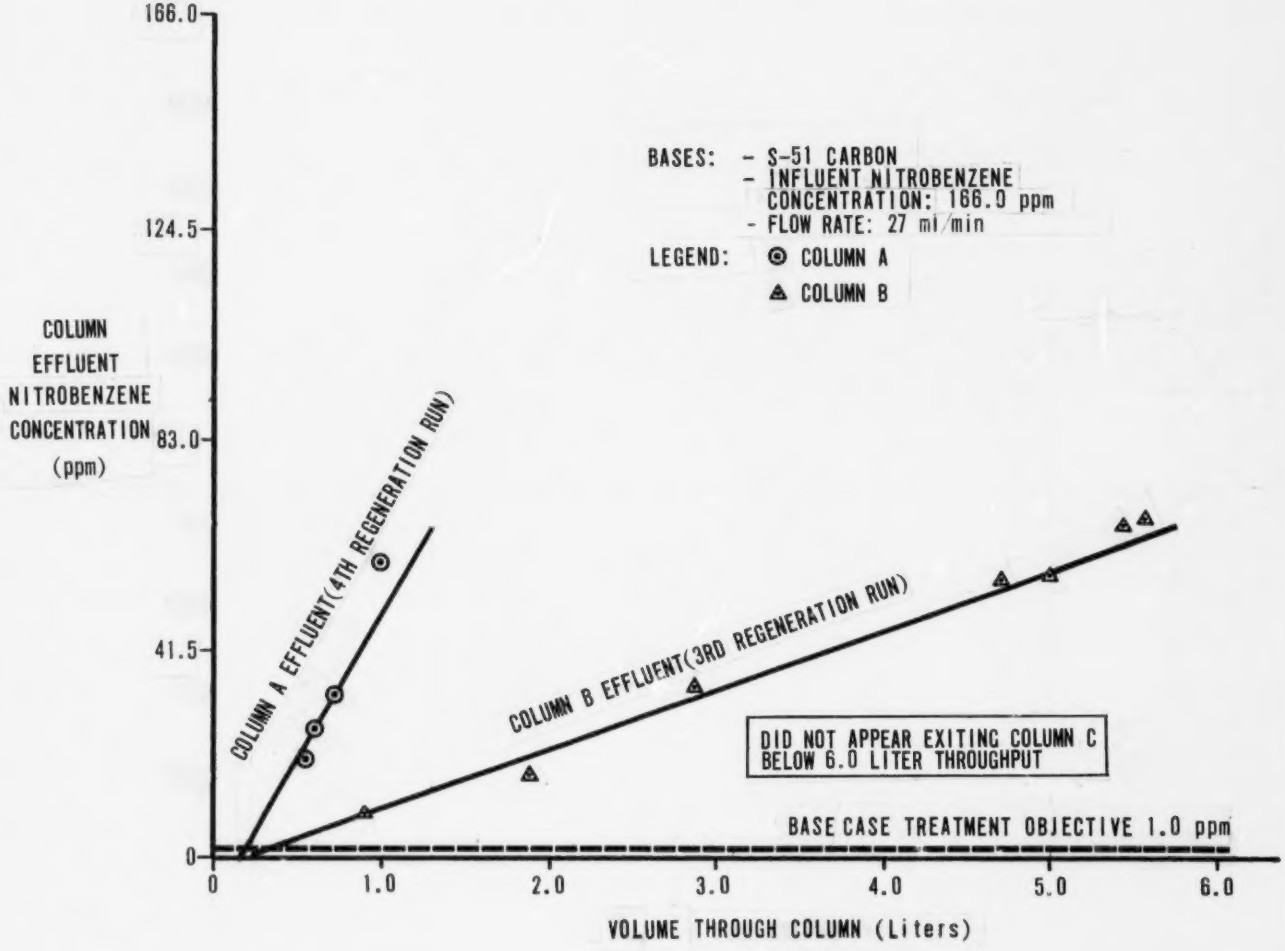

Figure 14. Nitrobenzene breakthrough.

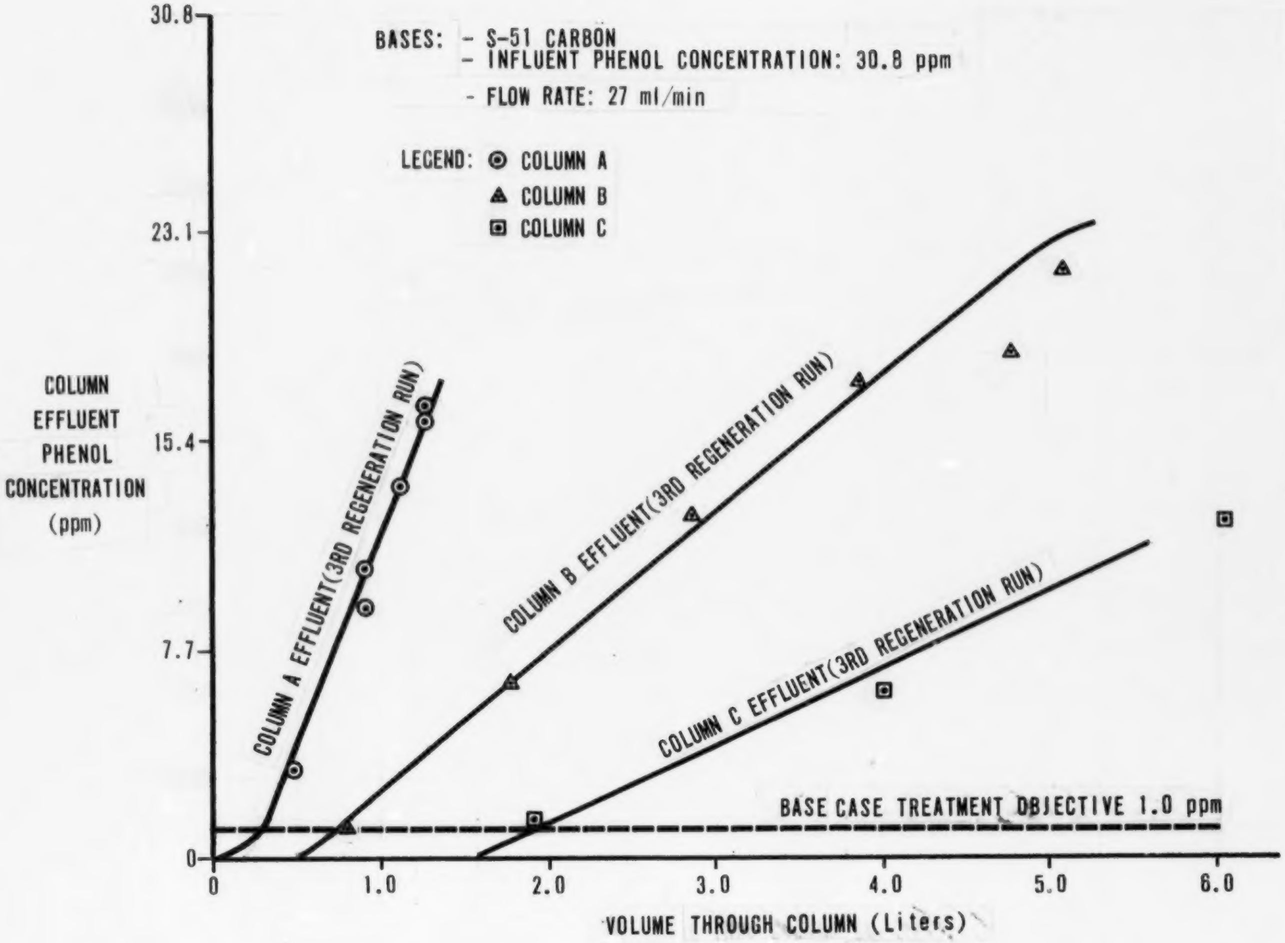

Figure 15. Phenol breakthrough.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-75)

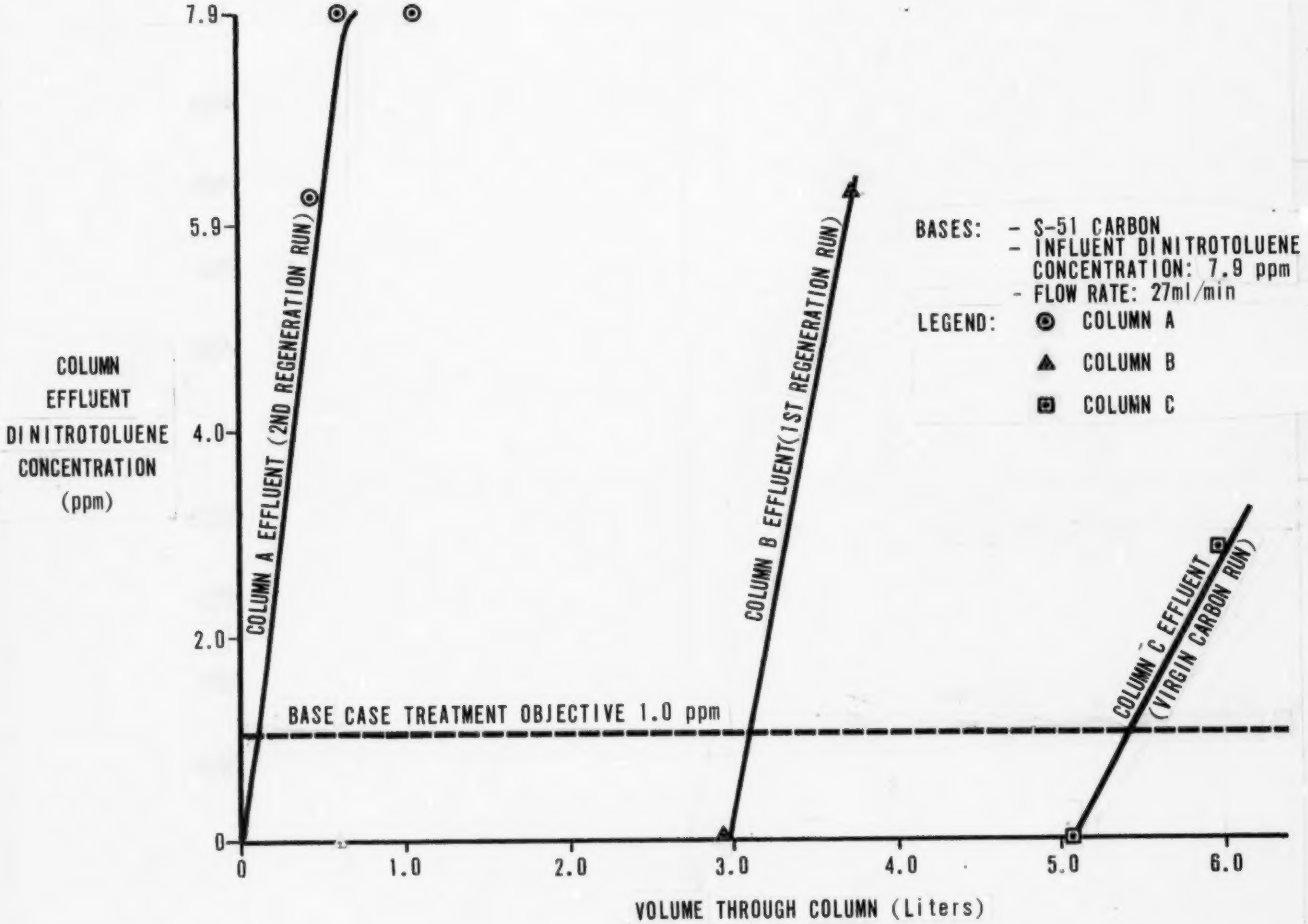

Figure 16. Dinitrotoluene breakthrough.

The breakthrough points indicated in these figures are where the column effluent exceeds a treatment objective of 1 ppm. Data were obtained in many cases until effluent values equaled influent concentration indicating that the carbon was saturated.

Treatment down to very low levels appears possible. The breakthrough curves are not precise, but are based on representative breakthrough column profiles selected from the dynamic test runs. It is felt that, considering the reliability of the laboratory analyses, these curves approximate the behavior of the pollutants in the dynamic column system and offer an adequate basis for economic screening studies. Additional dynamic data at and below the breakthrough points, and for longer residence times, would add confidence to the estimations.

Exhaustion Rates

The exhaustion rate is the amount of carbon required to treat a given volume of influent to a specific level. The system residence time, along with the total volumetric flow rate, defines the size of the adsorption system. Volumes of acceptable effluent collected were determined from the breakthrough curves. Exhaustion rates were determined for 10 ppm, 1 ppm and 0.1 ppm effluent concentration limits for each contaminant at 0.304, 0.608, 0.912 meters (one, two and three foot) bed depths. Also, from the isotherm graphs, a minimum carbon exhaustion rate based on influent concentration and infinite residence time was calculated. This information established an asymptotic portion of the exhaustion rate curve; however, it was based on virgin, not regenerated, carbon. The relationships between carbon exhaustion rates and superficial residence times for each pollutant are indicated in Figures 17 through 21.

XAD-4 RESIN STUDIES

Equilibrium Isotherm Results

Results of equilibrium isotherm studies are reported in Table 17A in the Appendix. Isotherm plots of the reduction in organic content (Figure 22) show a low intercept and steep slope, which indicate fairly low capacity at low concentrations and significant capacity increases at higher waste stream concentrations. Reducing the pH of the waste stream to a pH of 6 improves the adsorption performance in the same manner observed with carbon.

The isotherm results for the five priority pollutants at a pH of 9 are depicted in Figure 23. These data indicate that phenol and dichlorobenzene should be observed early in a continuous column effluent, since resin capacity is low for these compounds at the higher concentration levels. Dinitrotoluene does not appear to be adsorbed well as concentration decreases.

EPA-287 (Cin.)
(4-76)

TO1

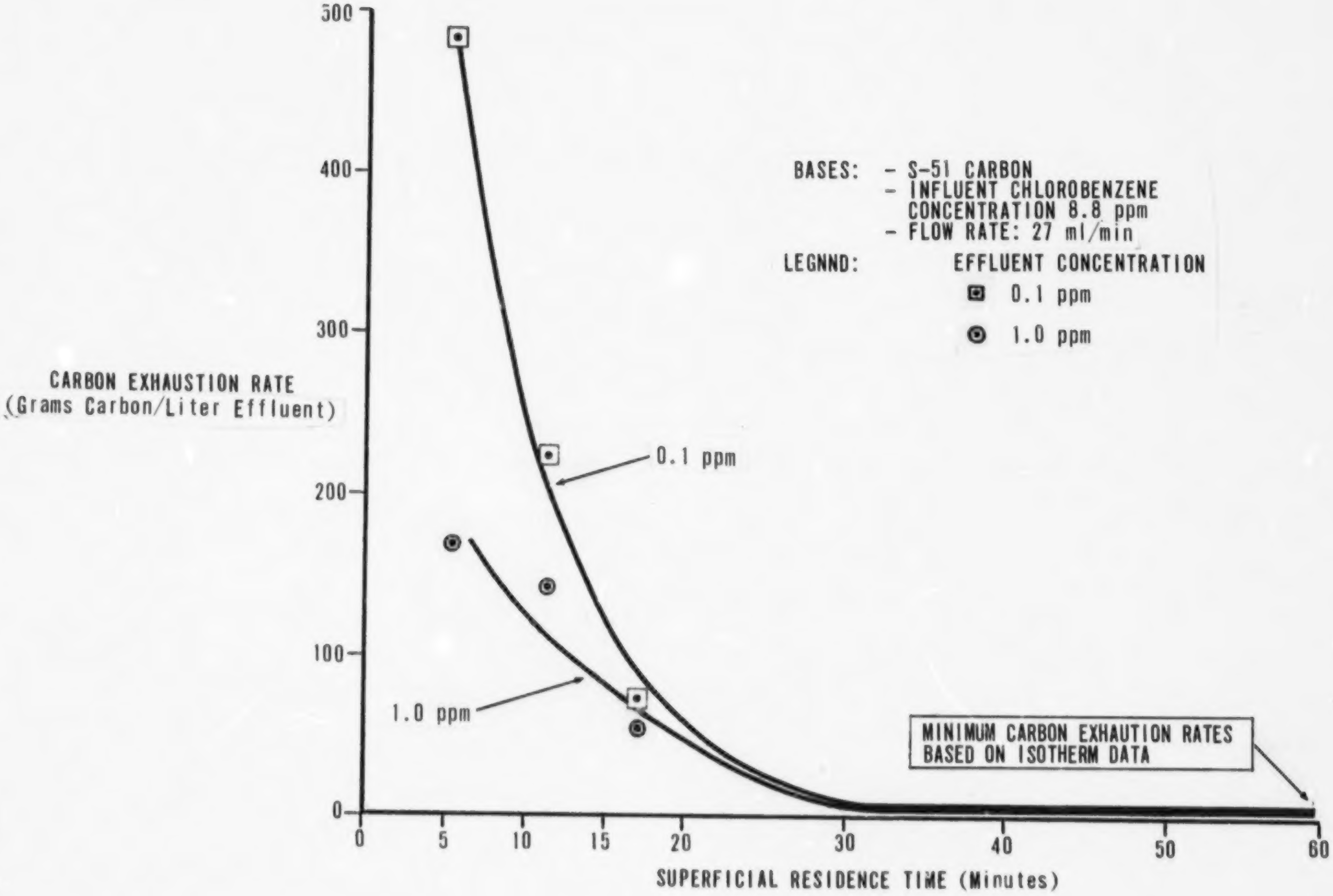

Figure 17. Chlorobenzene - carbon exhaustion rate vs. superficial residence time.

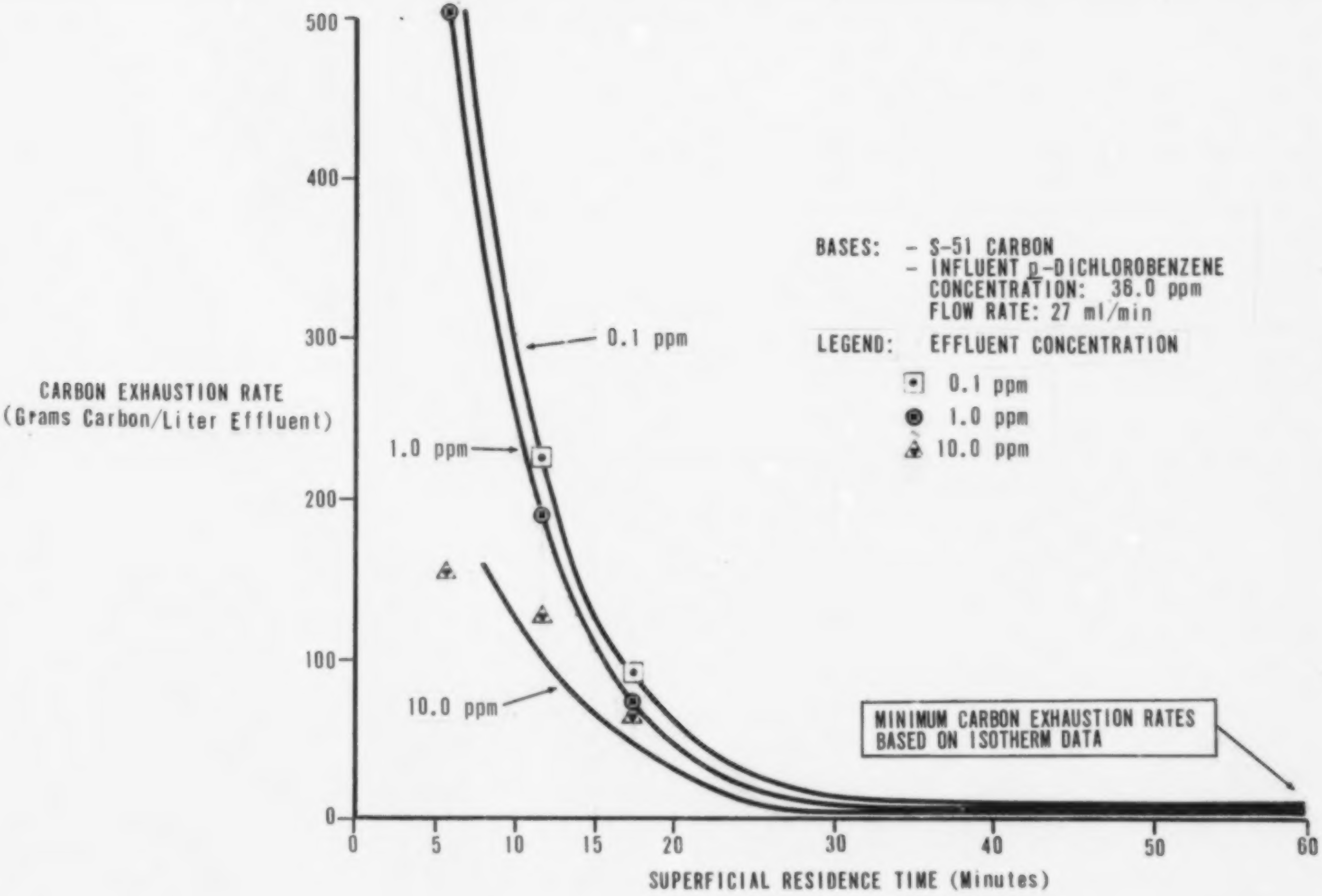

Figure 18. p-Dichlorobenzene - carbon exhaustion rate vs. superficial residence time.

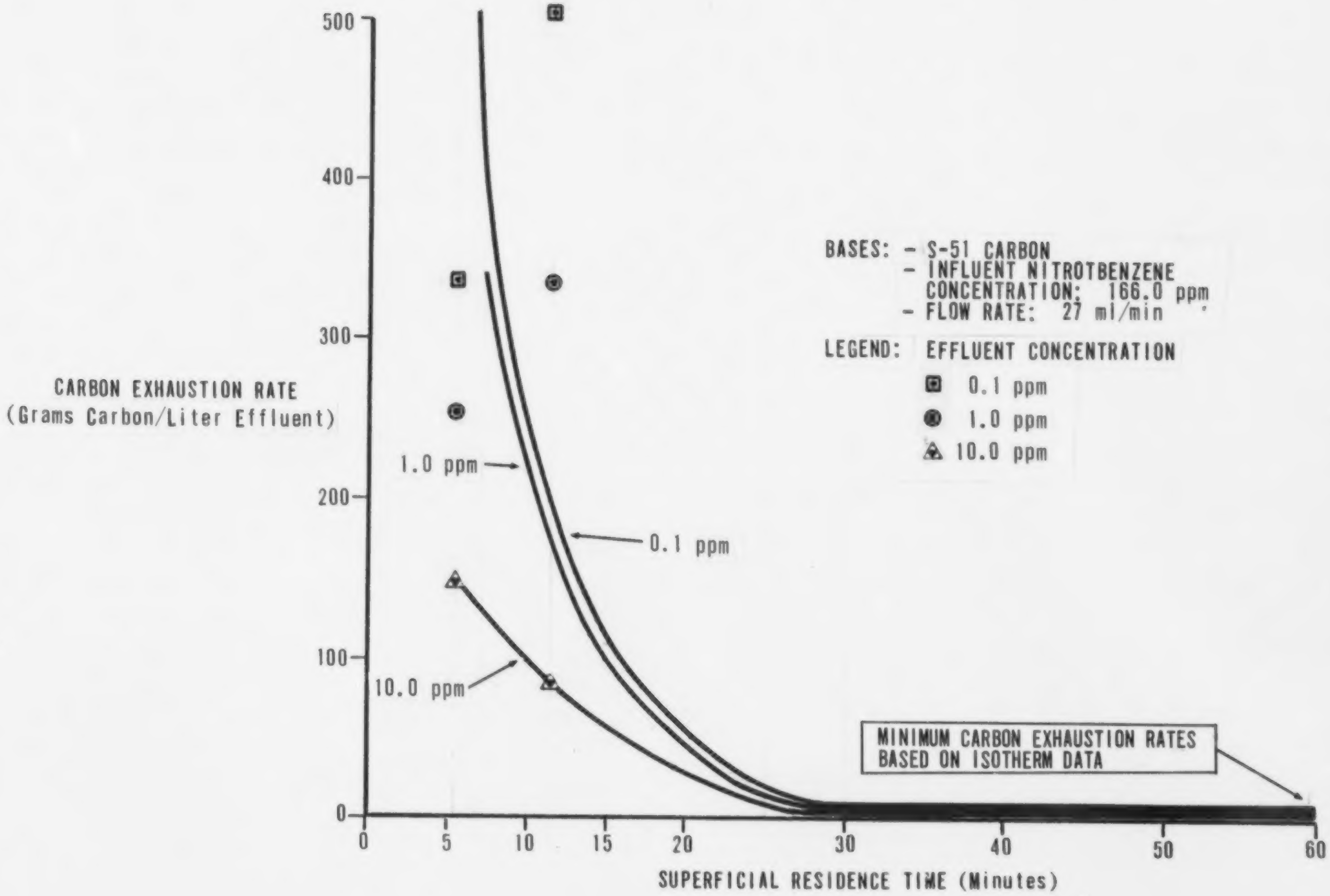

Figure 19. Nitrobenzene - carbon exhaustion rate vs. superficial residence time.

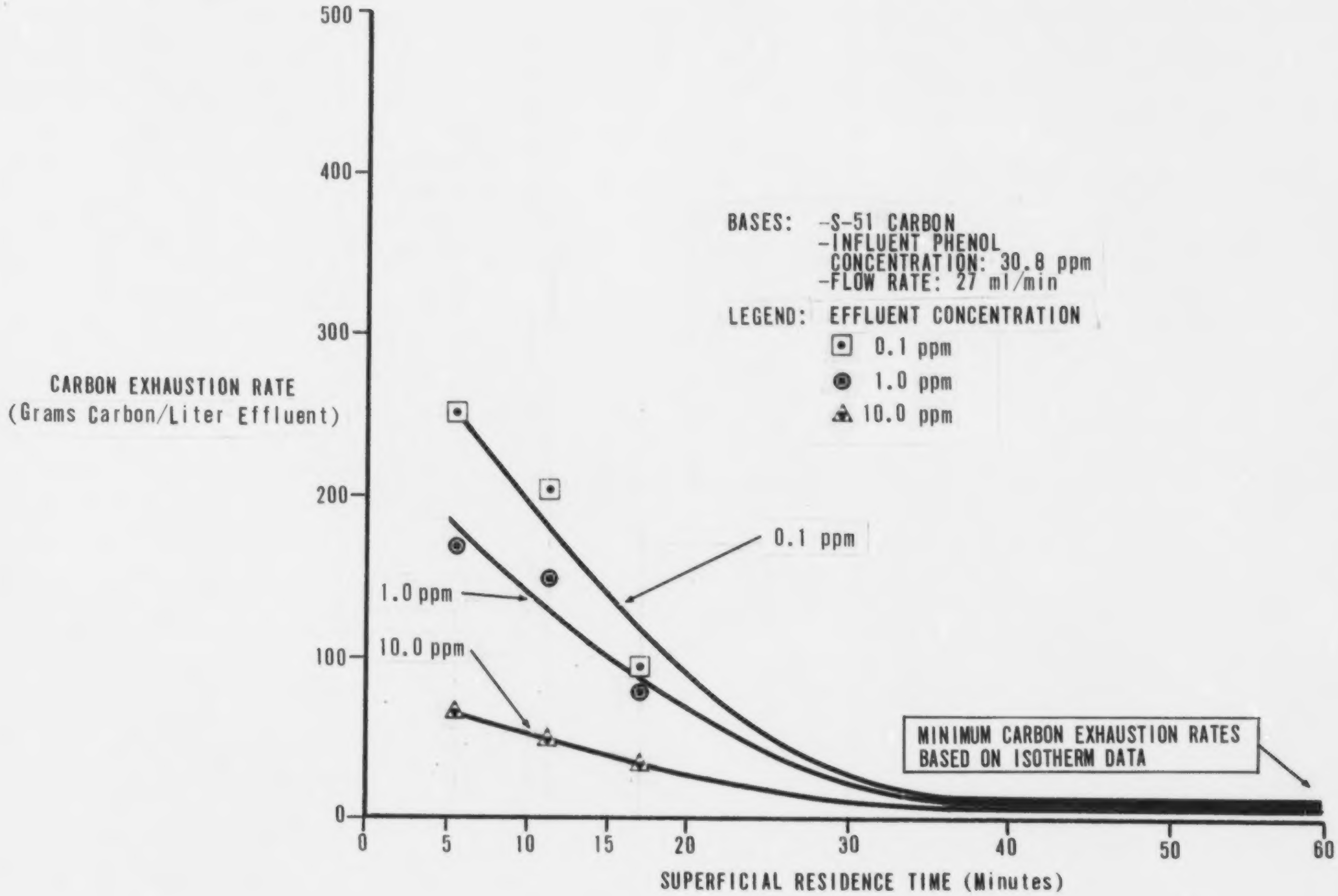

Figure 20. Phenol - carbon exhaustion rate vs. superficial residence time.

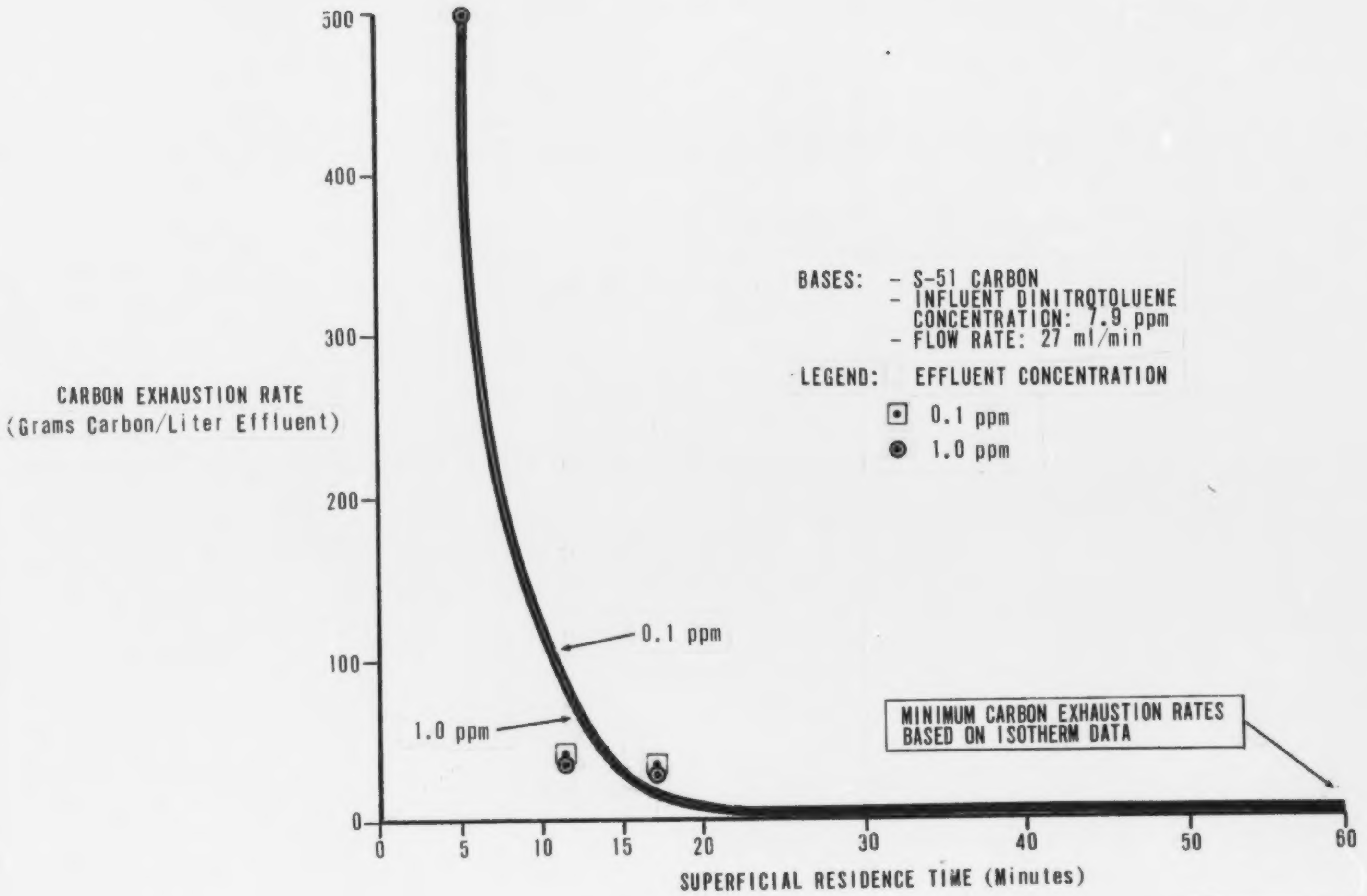

Figure 21. Dinitrotoluene - carbon exhaustion rate vs. superficial residence time.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

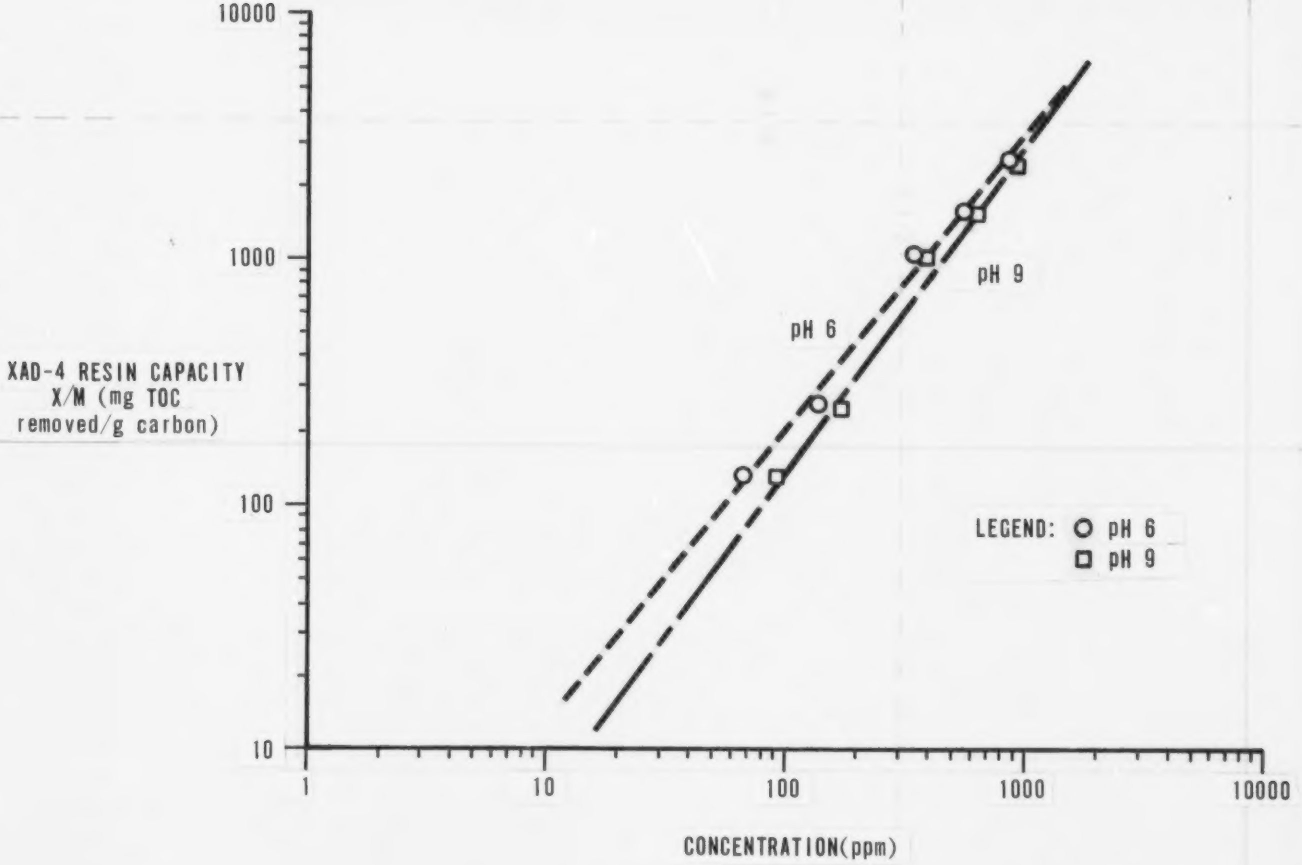

Figure 22. Equilibrium isotherm study using XAD-4 resin based on Dohrman Model 54 Analyzer data.

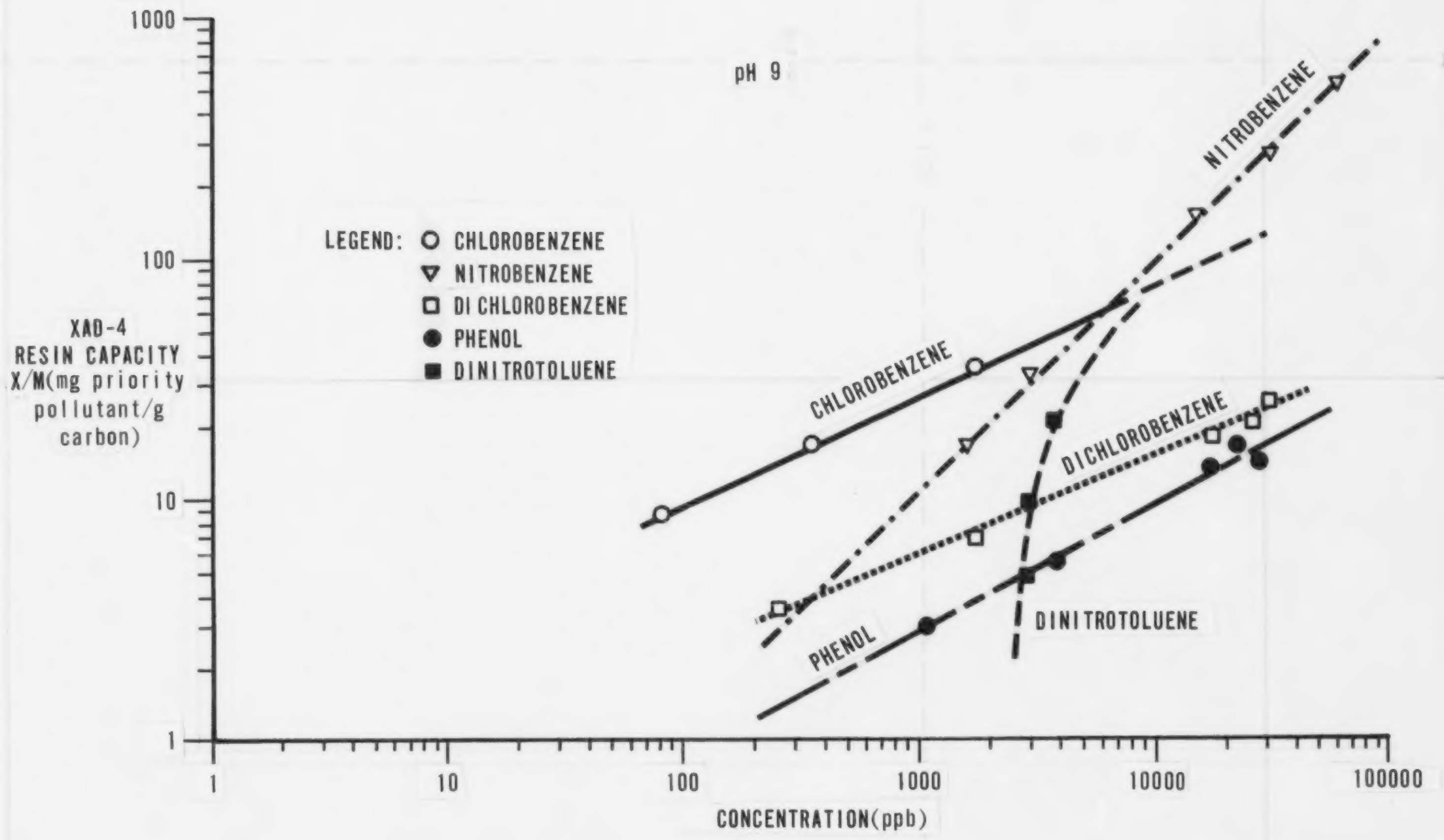

Figure 23. XAD-4 resin isotherm studies - priority pollutant reduction from an industrial waste stream.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (C
(4-76)

A comparison of the XAD-4 resin with S-51 activated carbon (Figure 24) indicates that the carbon and resin have similar potential loadings for gross organic contaminants as measured by TOC. The resin reflects a greater concentration sensitivity then the carbon. At high feed concentrations, the resin should be more effective in removal of the priority pollutants. As the concentration of the priority pollutants in the effluent stream decreases the loading of the carbon exceeds the loading of the resin.

Dynamic Studies

Results of the series of six runs performed with resin (initiated with virgin resin and followed with five methanol regeneration studies) are reported in Tables 18A through 23A of the Appendix. The TOC breakthrough profiles are depicted in Figure 25. An appearance of some organic material, approximately 3 percent of the feed stream, is observed almost from the beginning run. The leakage appears to be relatively constant.

Column performance actually improved through the first two regenerations, with some decrease observed from the third through the fifth regeneration, as shown in Figure 25. The original capacity of the column was still available after the fifth regeneration, however. These data are shown in Table 6.

Based on examination of individual component breakthrough data, p-dichlorobenzene was found to be the first of the five evaluated components to exceed 1.0 ppm in the effluent. This was true through the series of adsorption runs made with successive resin regenerations. The data indicate an effluent content of p-dichlorobenzene of 1.0 ppm after a column throughput equivalent to 21 bed volumes. Figures 26 and 27 present this breakthrough data and clearly indicate other treatment levels (lower or higher effluent concentrations) can be achieved with only small differences in throughput volume. TOC also broke through at about the same throughput.

Adsorptive capacity variation through successive regenerations is also shown in Figure 28 based on 1 ppm breakthrough of p-dichlorobenzene. The rise in activity through the first three runs is abnormal for this type of system and may indicate continued resin wash pre-conditioning through successive solvent regenerations.

In an effort to better define initial preparation of the resin, an additional run was performed with new resin that was washed with methanol equivalent to the methanol treatments through the third regeneration. An improvement in initial adsorption was observed (Table 24A in Appendix; summarized in Table 6). This initial adsorption capacity was still less than the capacity after the previously described regeneration cycles. The priority pollutants, other than dinitrotoluene, were generally not observed in the effluent prior to TOC breakthrough.

STEAM STRIPPING

The results of the batch distillation test are reported in Table 7. These data indicate that the less polar, lower boiling priority pollutants may be reduced

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

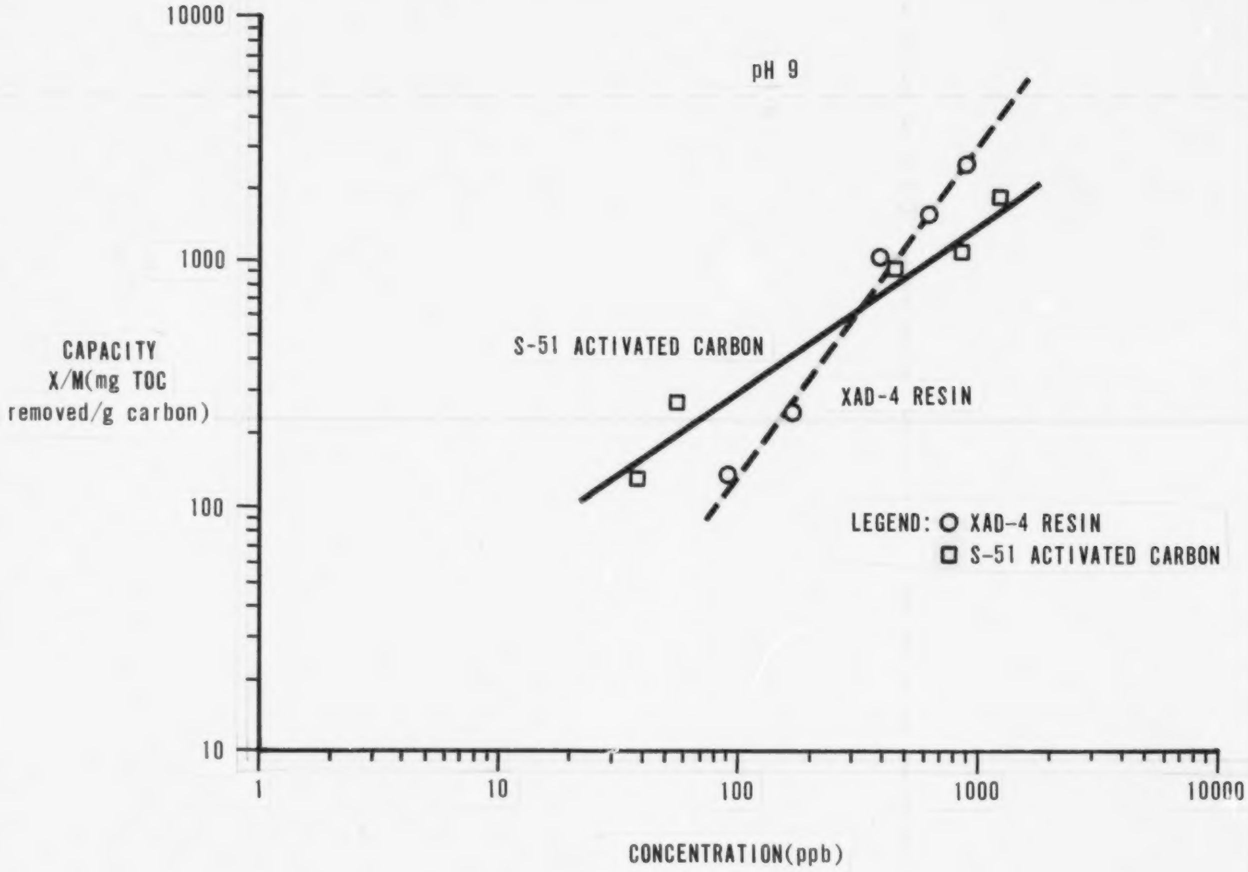

Figure 24. Isotherm studies comparing performance of S-51 activated carbon and XAD-4 resin based on Dohrman Model 54 Analyzer data.

TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE

DROPPED HEAD; BEGIN SECTIONS HERE

CENTER OF PAGE

TOP OF IMAGE AREA

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

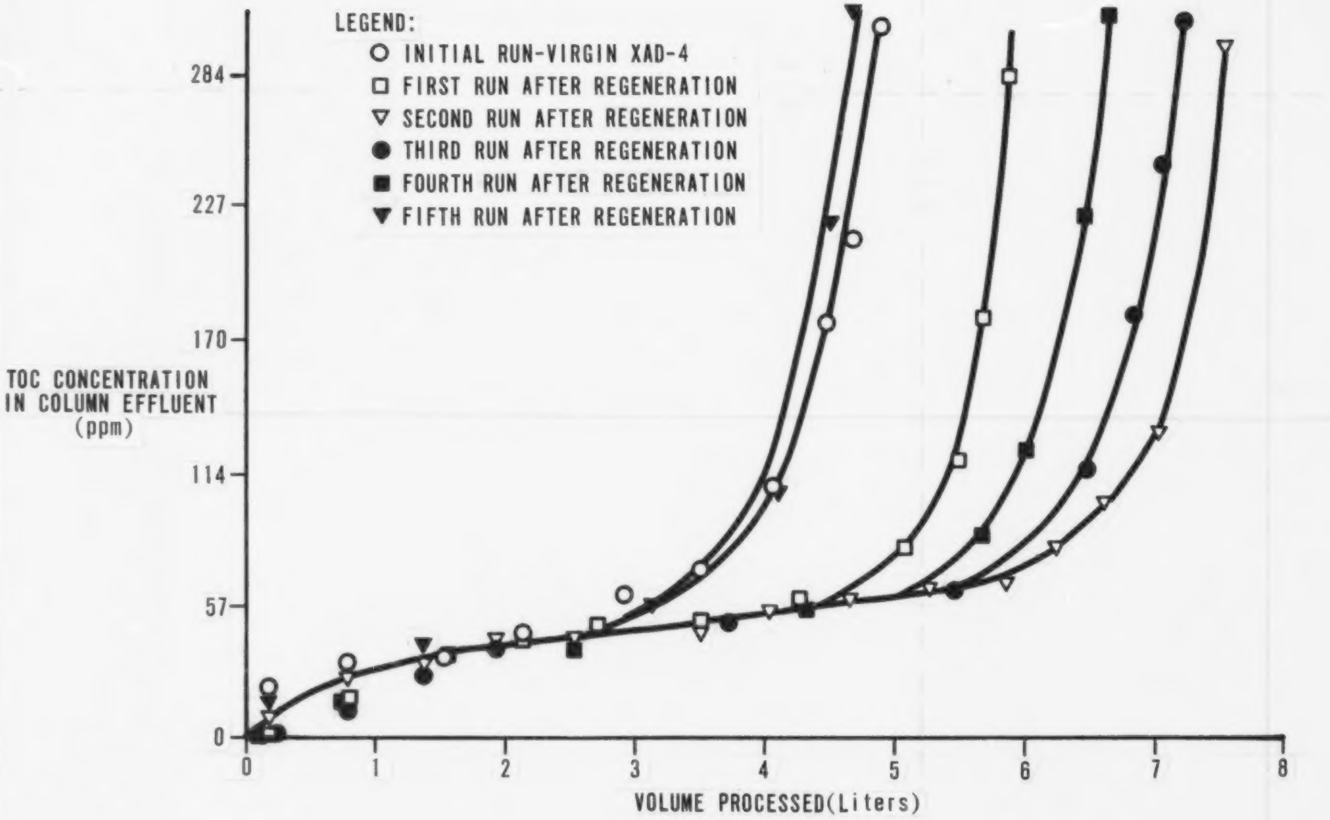

Figure 25. Adsorption column performance of XAD-4 resin with methanol regeneration.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 6.
XAD-4 PERFORMANCE THROUGH FIVE REGENERATION CYCLES

Run	Volume Processed to 20 Percent (284 ppm) TOC Breakthrough	Mass Organics Removed (g) (Influent TOC = 1418 ppm)	Mass Organics Removed/ Mass Resin (Mass Resin = 114 g)
Virgin Resin	4.8	6.8	0.060
First Regeneration	5.9	8.3	0.073
Second Regeneration	7.5	10.6	0.093
Third Regeneration	7.2	10.1	0.089
Fourth Regeneration	6.6	9.4	0.082
Fifth Regeneration	4.7	6.6	0.058
Virgin Resin (3X normal preparation)	6.0	8.5	0.075

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

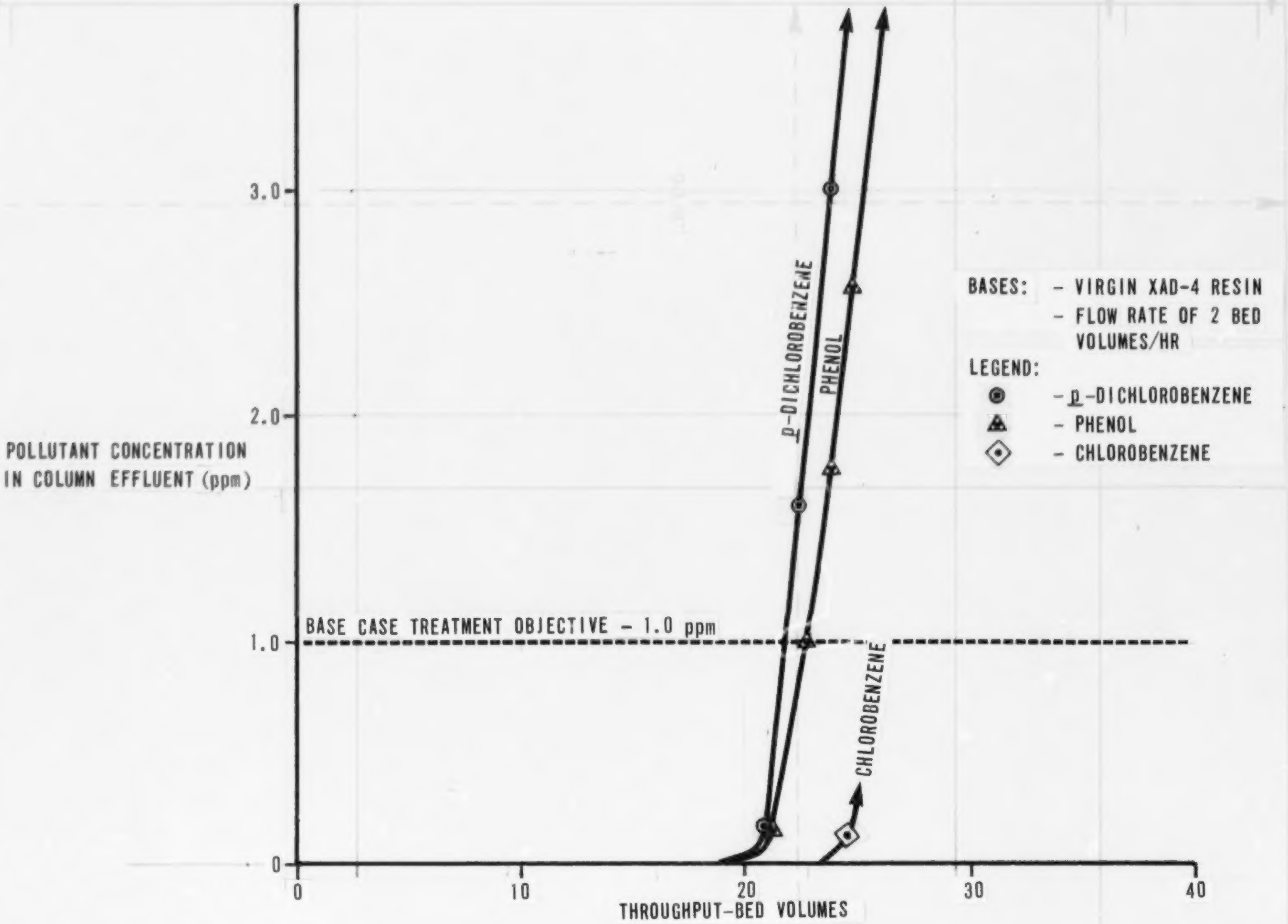

Figure 26. Pollutant breakthrough curves for virgin resin.

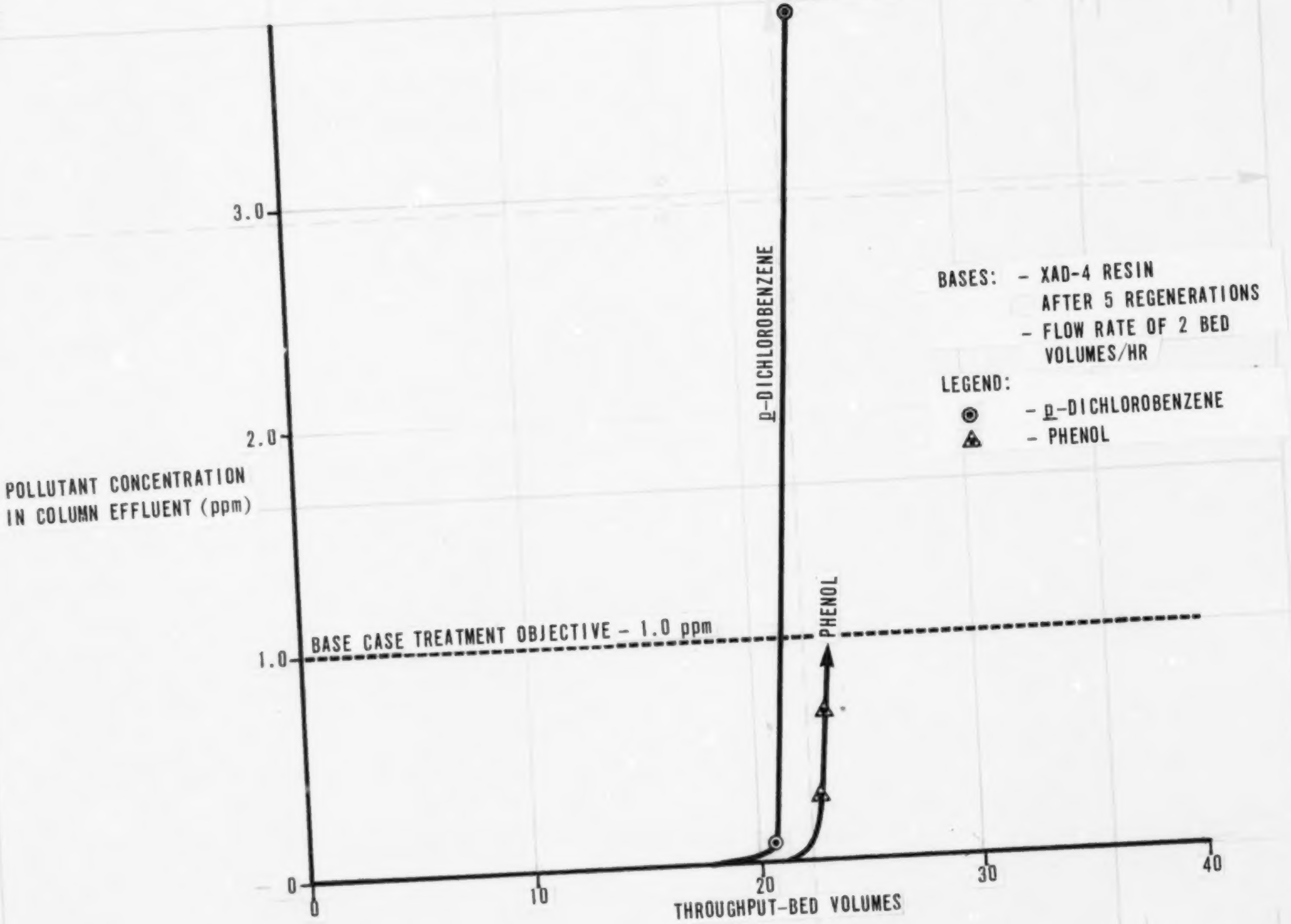

Figure 27. Pollutant breakthrough curves after 5 resin regenerations.

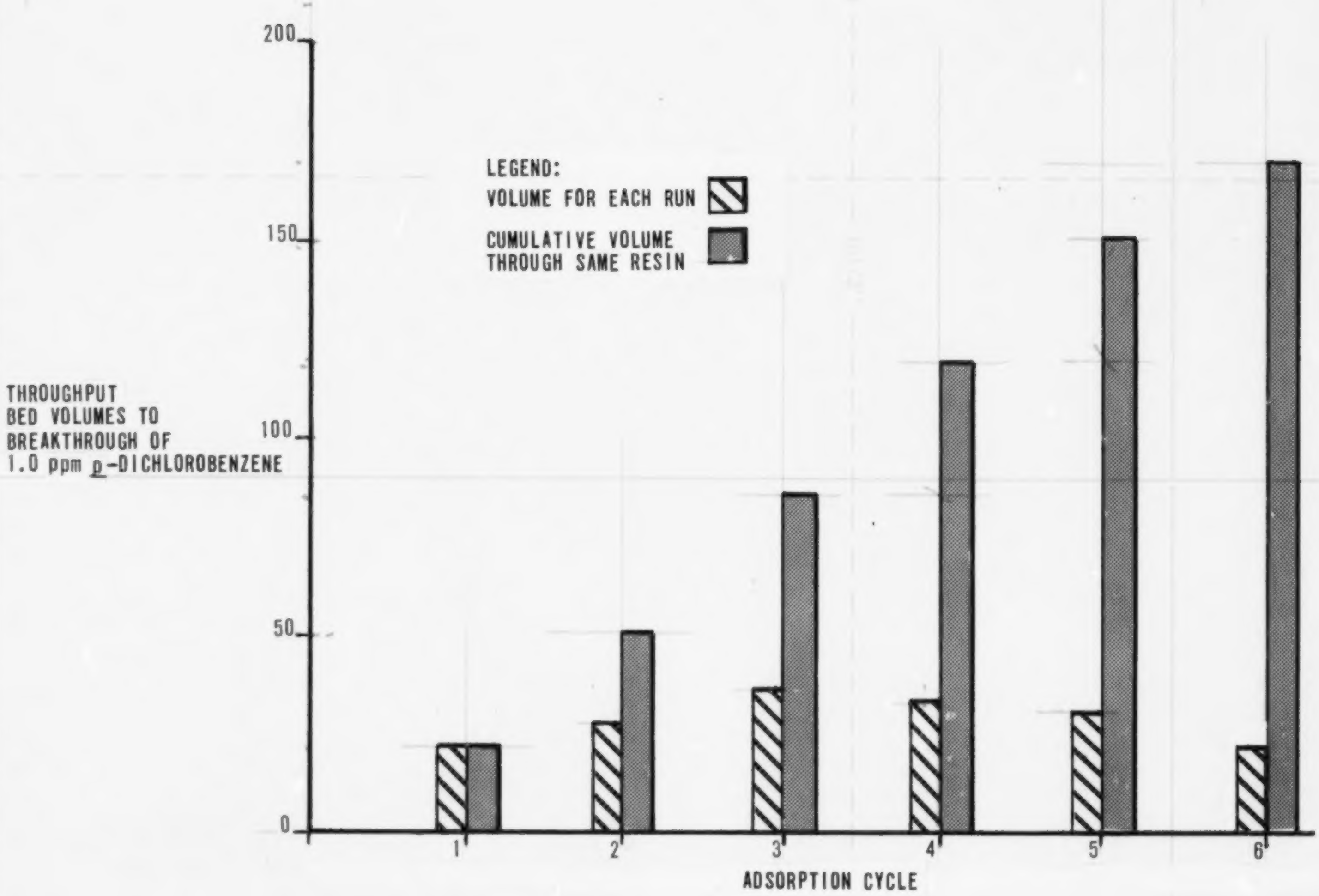

Figure 28. Resin adsorption capacity.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 7
INITIAL DISTRIBUTION OF POLLUTANTS IN BATCH DISTILLATION TEST
(Concentration in ppm)

Priority Pollutant	Initial Concentration	Final Concentration	Organic Phase Recovered Top of Column	Aqueous Return Top of Column
Chlorobenzene	8.8	4.1	5,800	32.3
p-Dichlorobenzene	36.0	13.1	37,900	377.0
Nitrobenzene	166.0	5.0	369,000	358.0
Aniline	1,330.0	1,050.0	592,000	200.0 (estimated)
Phenol	30.8	29.0	Not Detected	64.0
Dinitrotoluene	7.9	6.9	3400	5.1

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

significantly by steam stripping as reflected in the distributions of chloro-, dichloro-, and nitrobenzene. The major constituent, aniline, is reduced approximately 25 percent in the initial split. The higher boiling, more polar priority pollutants, phenol and dinitrotoluene were not effectively removed in the distillation experiment.

Three continuous stripping studies were performed. Process conditions are reported in Table 8. The first two runs were the same within the limits of experimental control. A significant change in the reflux to feed ratio was obtained in the third run by reducing the feed rate. It was necessary to reduce the preheat temperature with the lower flow rate to avoid degassing and vaporization in the preheater.

The distribution of priority pollutants obtained in the continuous stripping studies is reported in Table 9. Nitrobenzene was the major constitiuent in the organic phase effluent. The data indicate that the ratio of nitrobenzene to other constituents, particularly aniline, may be reduced as the feed rate is lowered, with aniline and dichlorobenzene ratios increasing. Major reductions in concentration were obtained in all cases for nitrobenzene and chlorobenzene. Reductions were also observed for dichlorobenzene and aniline. Phenol and dinitrotoluene were not removed effectively by steam stripping under the test conditions.

Material balances based on the batch and the continuous bench tests were compared to the results of a theoretical calculation which attempted to predict the laboratory results. Properties used in the theoretical calculations are presented in Table 10. These comparisons are shown in Table 11.

It should be emphasized that the results of the laboratory steam stripping tests are considered approximate. Variables such as column efficiency, flow distribution in the packed bed, height of transfer units, loading and flooding, reflux ratio, and condensation temperature have not been studied. Although there are some differences, results indicate that theoretical and test values compare reasonably well.

EPA-287 (Cin.)
(4-76)

TABLE 8
PROCESS CONDITIONS FOR CONTINUOUS STEAM STRIPPING STUDIES

	Run Number		
	1	2	3
Feed Rate (ml/min)	123	115	78
Reflux Rate (ml/min)	10.0	9.5	7.8
Ratio (reflux rate to feed rate)	0.080	0.083	0.100
Preheat Feed Temperature (^{o}C)	75.4	75.6	64.8
Distillation Column Overhead Temperature (^{o}C)	109.5	110.2	116.0
Reboiler Temperature (^{o}C)	99.5	99.5	99.5
Duration of Run (min)	30	30	30
Volume of Collected Organic Phase (ml)	0.95	0.85	0.60

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 9
DISTRIBUTION OF PRIORITY POLLUTANTS IN CONTINUOUS STEAM STRIPPING STUDIES
(Concentration in ppm)

Ratio, Reflux to Feed Rate	Pollutant	Average Feed Concentration	Column Bottoms	Organic phase Recovered, Top of Column	Aqueous Phase Return, Top of Column
0.080	Chlorobenzene	8.8	2.0	13,960	9.5
	p-Dichlorobenzene	36.4	21.4	14,200	1,350
	Nitrobenzene	166.0	15.7	817,000	1,390
	Aniline	1,329	1,150	195,000	10,760
	Phenol	30.8	34.6	704	784
	Dinitrotoluene	7.9	9.7	6,530	Not detected
0.083	Chlorobenzene	8.8	0.7	16,940	4.1
	p-Dichlorobenzene	36.4	27.8	13,000	1,350
	Nitrobenzene	166.0	8.3	796,000	1,390
	Aniline	1,329	890	185,000	9,100
	Phenol	30.8	28.0	508	50.2
	Dinitrotoluene	7.9	7.8	7,500	4.7
0.100	Chlorobenzene	8.8	>0.1	10,400	7.0
	p-Dichlorobenzene	36.4	21.2	23,400	1,930
	Nitrobenzene	36.4	21.2	654,000	1,930
	Aniline	1,329	773	248,000	11,820
	Phenol	30.8	28.0	900	44.2
	Dinitrotoluene	7.9	5.6	5,080	Not detected

EPA-287 (Cin.)
(4-76)

TABLE 10
SELECTED PROPERTIES OF POLLUTANTS STUDIED

COMPONENT	Equilibrium Coefficient,(K)	Activity Coefficient,(γ)	Solubility(g/l)
Chlorobenzene	727.7(a)	1,907(a)	0.49(a)
p-Dichlorobenzene	1,364(a)	19,200(b)	0.79(a)
Nitrobenzene	16.6(a)	621(a)	1.9(a)
Aniline	6.53(c,g)	110.3(d)	0.37(e)
Phenol	2.26(a)	43(f)	5(a)
Dinitrotoluene	17.9(a)	5,028(b)	0.285(a)

NOTES:
a - Hwang, 1979
b - Tsonopoulos, 1971
c - Gallant, 1970
d - Reid, 1977
e - Morrison, 1973
f - Gmehling, 1977
g - Assumed Raoult's Law and Calculated

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 11.
COMPARATIVE STRIPPING MATERIAL BALANCES (EXPERIMENTAL AND CALCULATED [a])

COMPONENT	FEED[b]	BATCH			CONTINUOUS			CALCULATED		
		Bottoms[b]	Distillate [e]		Bottoms[b]	Distillate [e]		Bottoms[b]	Distillate	
			(b)	(c)		(b)	(c)		(b)	(c)
Chlorobenzene	8.8	4.1	8,950	4.7	2.04	22,800	6.76	Trace	26,800	8.8
p-Dichlorobenzene	36.4	13.1	44,400	23.3	21.41	50,500	14.99	Trace	111,000	36.4
Nitrobenzene	166	5.0	307,000	161	15.37	507,000	150.6	31	416,000	135
Aniline	1,329	1,050	531,000	279	1,271	195,000	57.9	1,260	209,000	68.7
Phenol	30.8	29	3,430	1.8	30.6	673	0.2	30.65	457	0.15
Dinitrotoluene	7.9	6.9	1,900	1.0	5.96	6,530	1.94	0.4	22,900	7.5
Other Organics[d]	421	367	103,000	54.2	356	218,000	64.6	349	218,000	71.6

a) Basis: Calculation Made to Predict Laboratory Results

b) Parts Per Million

c) Parts Per Million Parts Feed

d) Estimated, from TOC Measurements

e) Adjusted to close material balance relative to feed and bottoms. G.C. at high concentrations judged least reliable.

SECTION 6

PROCESS DESIGN

In order to provide for later economic comparison, design studies for each of the three treatment technologies had the following common bases:

- A waste stream comparable to the sample tested (see Table 1).
- A 1,130 liters per minute waste stream flow rate.
- A treatment objective of 1 ppm in the final effluent for the "most difficult-to-remove priority pollutant".

CARBON ADSORPTION

Adsorption Columns

There are three alternatives available in selecting a design for a carbon adsorption process. These include the fixed-bed, the semi-continuous (or series) and the pulsed bed schemes. The fixed-bed and the semi-continuous schemes offer either upflow or gravity flow options and the pulsed bed requires an upflow operation. For upflow operations, the beds may operate in an expanded fashion which offers advantages if unfiltered solids are present in the influent.

In the fixed-bed scheme, one adsorber is on-line and a second is on standby, full of regenerated carbon. When the contamination level in the effluent from the on-line column rises to the predetermined standard, flow is switched to the standby column and the carbon is removed from the original column for regeneration or in some cases, is regenerated in situ. Generally the carbon is saturated based on the inlet feed at the bottom of the column, while the carbon higher in the bed contains progressively less pollutant. The laboratory data obtained applies to this type of design.

In a semi-continuous system, the total required column volume is divided into a series of beds. The operation of the beds is stepwise. When the effluent concentration from the last bed increases to an unacceptable value, a standby bed of fresh carbon is put on line at the end of the train. The feed to the train is directed from the first to the second bed. Because the spent carbon is removed in increments, its average pollutant concentration is higher than in a single bed scheme. Therefore, a semi-continuous system will have carbon usage rates lower than a single bed system (10).

In a pulsed bed system, the carbon is pulsed from the bottom of the adsorber, discharging a portion (5 to 10%) of the bed on each pulse. This is analogous to a semi-continuous system having ten to twenty columns, except that the pulsed bed arrangement simplifies the logistics. Depending on contact time, a 5% pulse is usually small enough to assure that essentially saturated carbon based on the influent is discharged from the column. This design is most effective for systems requiring large amounts of carbon as well as counter-current flow efficiency (2). Additionally, it provides a large safety factor, since there is always fresh carbon available in the system that can be immediately placed in the column if an unexpected breakthrough occurs.

Regeneration Systems

There are several currently acceptable options to consider in the selection of a method to replace exhausted carbon such as onetime use, offsite reactivation at the user's own facility, onsite reactivation or contractor service. One-time carbon use is unacceptable if carbon exhaustion rates are high. The laboratory data indicated that thermal carbon regeneration is preferred to the steam regeneration option. Additionally, thermal regeneration is the currently more acceptable industry-wide practice (11).

The thermal regeneration furnace is designed to drive off moisture from the carbon, then volatilize and oxidize the organic contaminants. Volatilization is normally conducted with less than 1 percent, by volume, of oxygen to reduce carbon loss by burning. Additionally, the furnace should include an afterburner and scrubber to eliminate the possibility of air pollution from the volatilized organics.

A typical thermal carbon regeneration system consists of a rotary kiln or multiple hearth furnace. Since it causes less mechanical damage to the material, the multiple hearth furnace presently provides the best procedure for removing organics from activated carbon (11).

Approximately 5 to 10 percent of the carbon is normally lost due to the furnace treatment and handling. It was not possible to evaluate attrition losses within the scope of the laboratory work.

The size of the regeneration system required depends on the carbon exhaustion rate. Excess capacity is normally provided for maintenance downtime and to handle the variations in the carbon usage that result from fluctuations in wastewater flow and organic loading.

Carbon Transport

Once carbon is introduced into the adsorption/regeneration system, carbon can be transported by using water or air pressure. The choice of motive power is generally established by user preference, differential head requirements and economics. Centrifugal pumps, eductors or diaphragm pumps provide the motive force for slurry systems. Centrifugal pumps are preferred for low slurry concentrations.

EPA-287 (Cin.)
(4-76)

Spent slurry can be dewatered mechanically through the use of screens, classifiers, or gravity separation. Dewatering screws are also satisfactory and eliminate the need for drain bins. However, they require spent carbon storage bins to provide constant feed to the screws.

Either bulk pneumatic or bagged methods can be employed in the handling of make-up carbon in an adsorption system. With the development of modern economical methods of handling bulk carbon, a bulk system is normally less expensive than bagged carbon, particularly if a rail siding is available at the plant site. However, if the quantity of make-up carbon is small, the savings of bulk delivery costs over bag delivery must be analyzed against the cost of receiving and storage facilites required for bulk shipment.

Both make-up and regenerated carbon must be washed before it is placed in the adsorption column in order to remove fine carbon dust which causes plugging and excessive pressure loss in the carbon bed. Carbon make-up tanks and the regenerated carbon tanks are equipped to process the carbon and remove fine particles from the system.

6-1/2"

System Design

A process arrangement for the cost evaluation of carbon adsorption is shown in Figure 29. An equipment list for the base case design is contained in Table 12.

9-1/8"

Column Design:

An upflow pulsed bed was selected to maximize the effect of counter current flow through the column. The high clarity influent required for such a system was accounted for by assuming that a filtration system already exists. Design studies included use of Darco S-51 carbon.

The carbon exhaustion rates and preliminary column sizing was based on the collected data for fixed-bed systems. Laboratory study of semi-continuous counter flow fixed-bed and pulsed bed contacting systems was precluded by time and cost considerations. Applying the existing data without modifications to these other contacting systems provides a conservative design. Actually, the pulsed bed unit, which is the basis for the economic study, would be smaller than the calculated size due to its greater efficiency, but the impact on total estimated cost is not large. The attainment of an essentially maximum saturation of carbon, through use of the pulsed bed, was important since it minimizes the high cost of regeneration.

The carbon exhaustion rates from Section 5 for each component were replotted on single graphs to determine the controlling pollutant. Figures 30 through 32 give the replotted data for 0.1, 1.0 and 10 ppm effluent concentrations. These three effluent levels will be used in the economic evaluation. Using these graphs, a residence time for adsorber system operation and a carbon exhaustion rate was obtained. The operating line for each of the pollutants under study flattens at greater residence times. The curves indicate that there is a point of

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

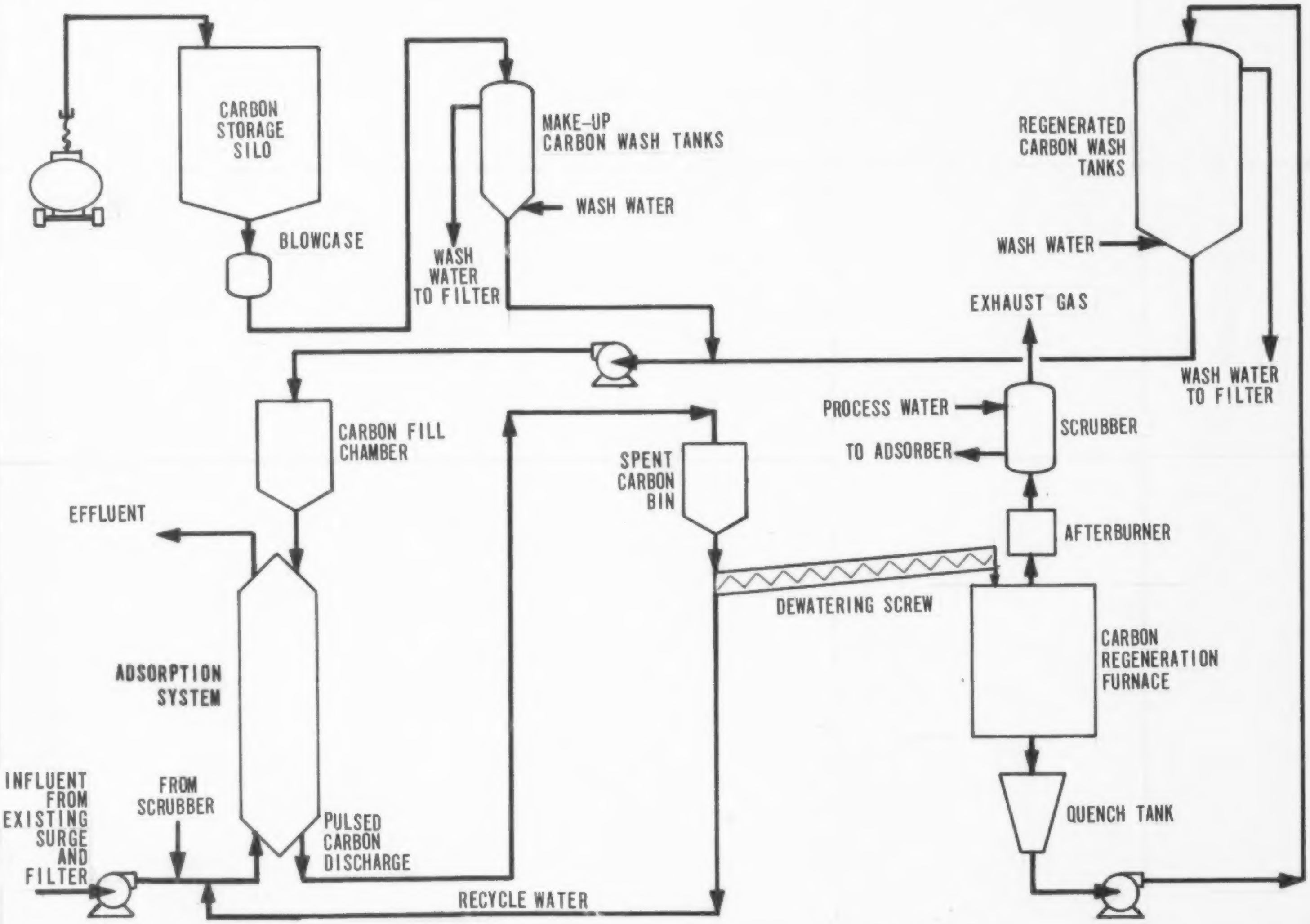
CARBON STORAGE SILO
BLOWCASE
MAKE-UP CARBON WASH TANKS
WASH WATER
WASH WATER TO FILTER
REGENERATED CARBON WASH TANKS
WASH WATER
EXHAUST GAS
WASH WATER TO FILTER
PROCESS WATER
SCRUBBER
TO ADSORBER
CARBON FILL CHAMBER
SPENT CARBON BIN
EFFLUENT
AFTERBURNER
DEWATERING SCREW
CARBON REGENERATION FURNACE
ADSORPTION SYSTEM
INFLUENT FROM EXISTING SURGE AND FILTER
FROM SCRUBBER
PULSED CARBON DISCHARGE
QUENCH TANK
RECYCLE WATER

Figure 29. Process flow - carbon adsorption/regeneration system.

TABLE 12
EQUIPMENT LIST - CARBON ABSORPTION

ITEM	FUNCTION	NUMBER	DESCRIPTION
Column	Adsorption	1	3.1 m (10 ft.) diameter x 7.6 m (25 ft.) high
Bin	Spent carbon	1	10.8 m^3 (380ft.^{3}) volume
Screw conveyor	Carbon transfer/dewatering	1	15.2 cm (6 in.) diameter x 9.2 m (30 ft.) length
Furnace	Regeneration	1	130.2 m^2 (1,400 ft.^{2}) multihearth with afterburner and scrubber
Tank	Quenching	1	7.6 m^3 (270 ft.^{3}) volume
Tank	Regenerated carbon wash	3	7.6 m^3 (270 ft.^{3}) volume
Chamber	Carbon fill	1	10.8 m^3 (380 ft.^{3}) volume
Tank	Make-up carbon wash	2	0.6 m^3 (20ft.^{3}) volume
Silo	Carbon storage	1	3,540 m^3 (125,000ft.^{3}) volume
Pump	Influent	2	1,130 l/min (300gpm) 138kPa (20psi), 7.45 kw (10hp)
Pump	Carbon Transfer	4	190 l/min (50gpm), 69kPa (10psi), 1.5 kw (2hp)
Pump	Scrubber bottoms	2	378 l/min (100 gpm), 69kPa (10psi), 3.7 kw (5hp) centrifugal

Basis: 1,130 l/min (300 gpm) throughput, treatment to 1.0 ppm phenol.

EPA-287 (Cin.)
(4-76)

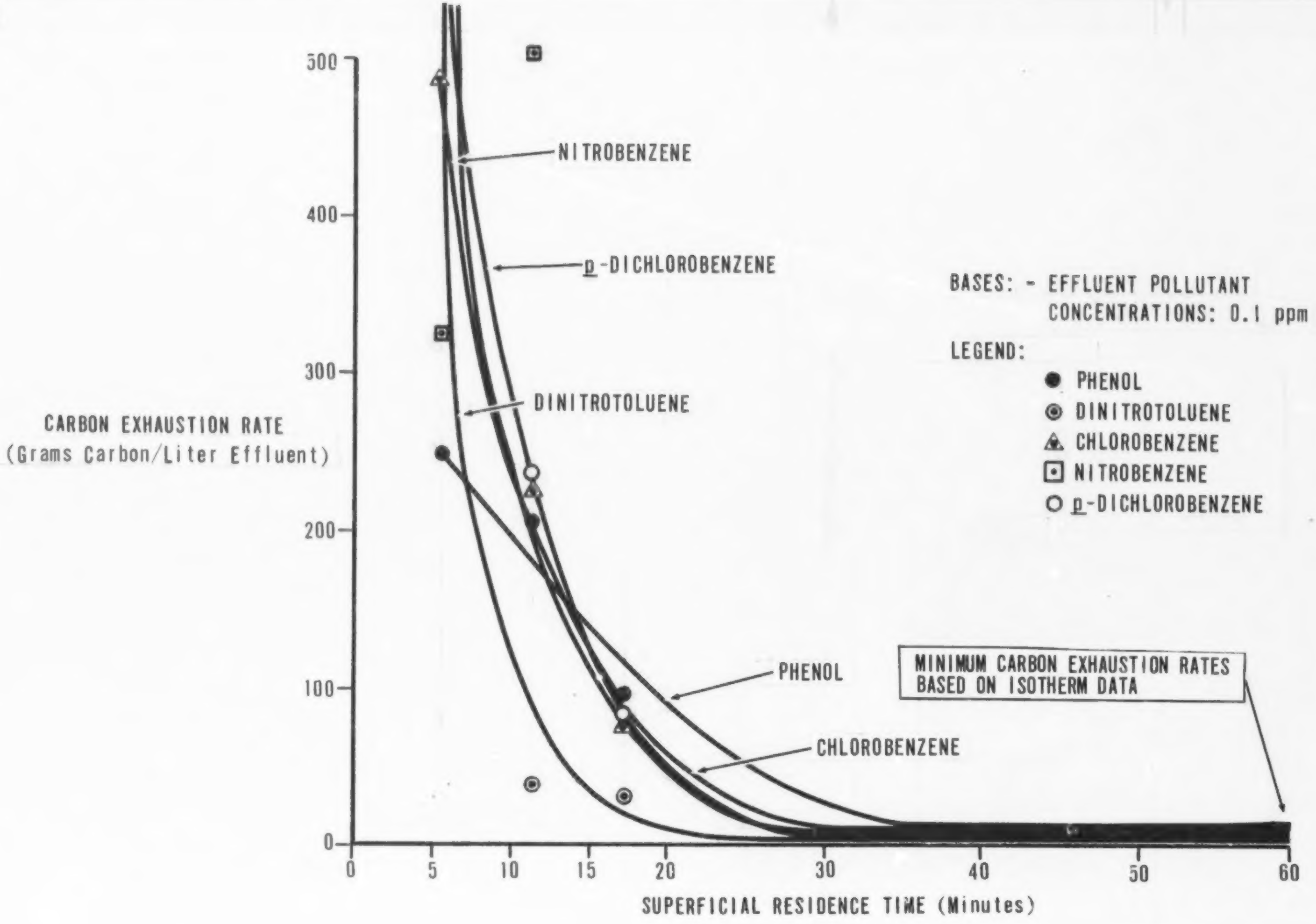

Figure 30. Carbon exhaustion rate vs. superficial residence time - effluent concentration 0.1 ppm.

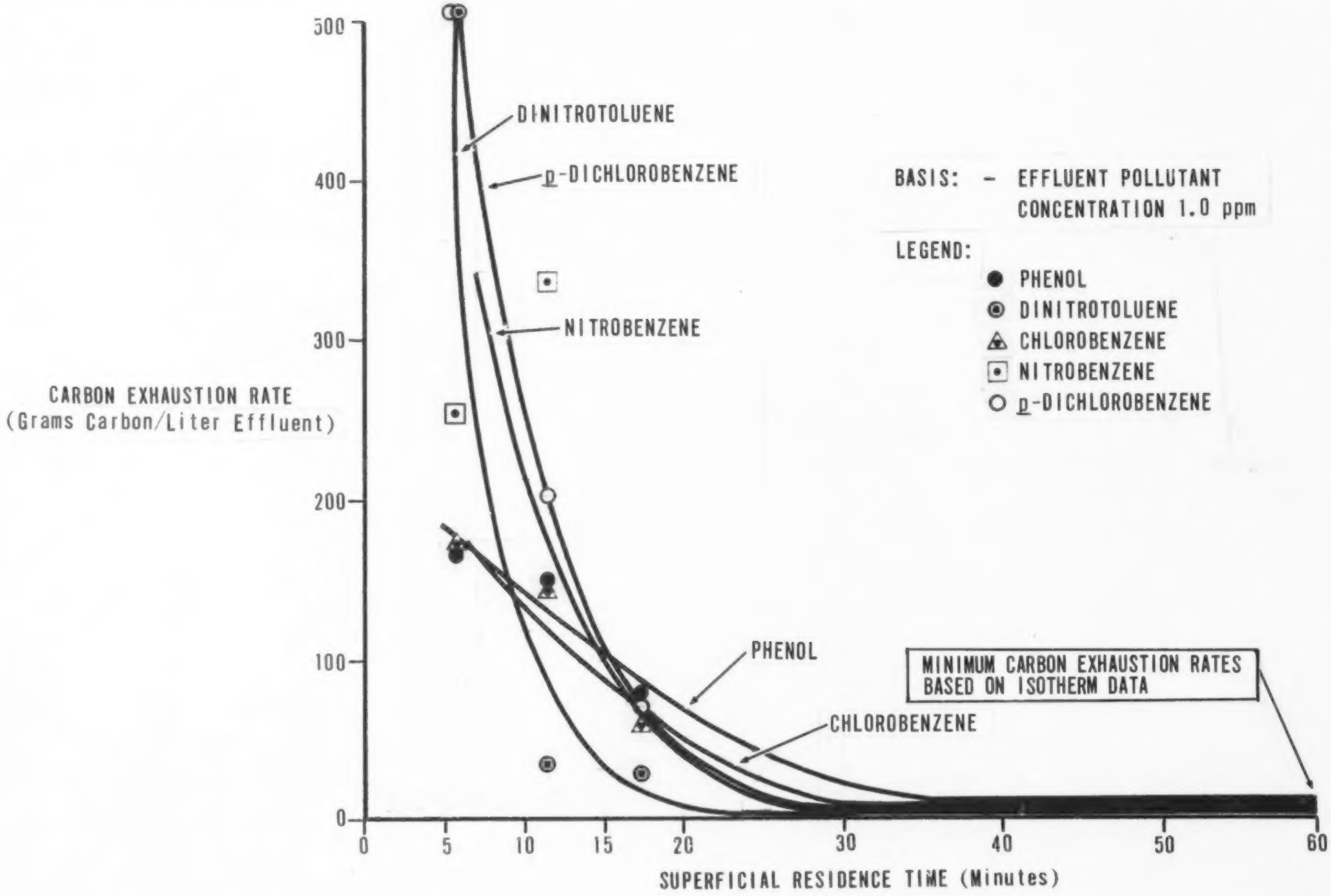

Figure 31. Carbon exhaustion rate vs. superficial residence time - effluent concentration 1.0 ppm.

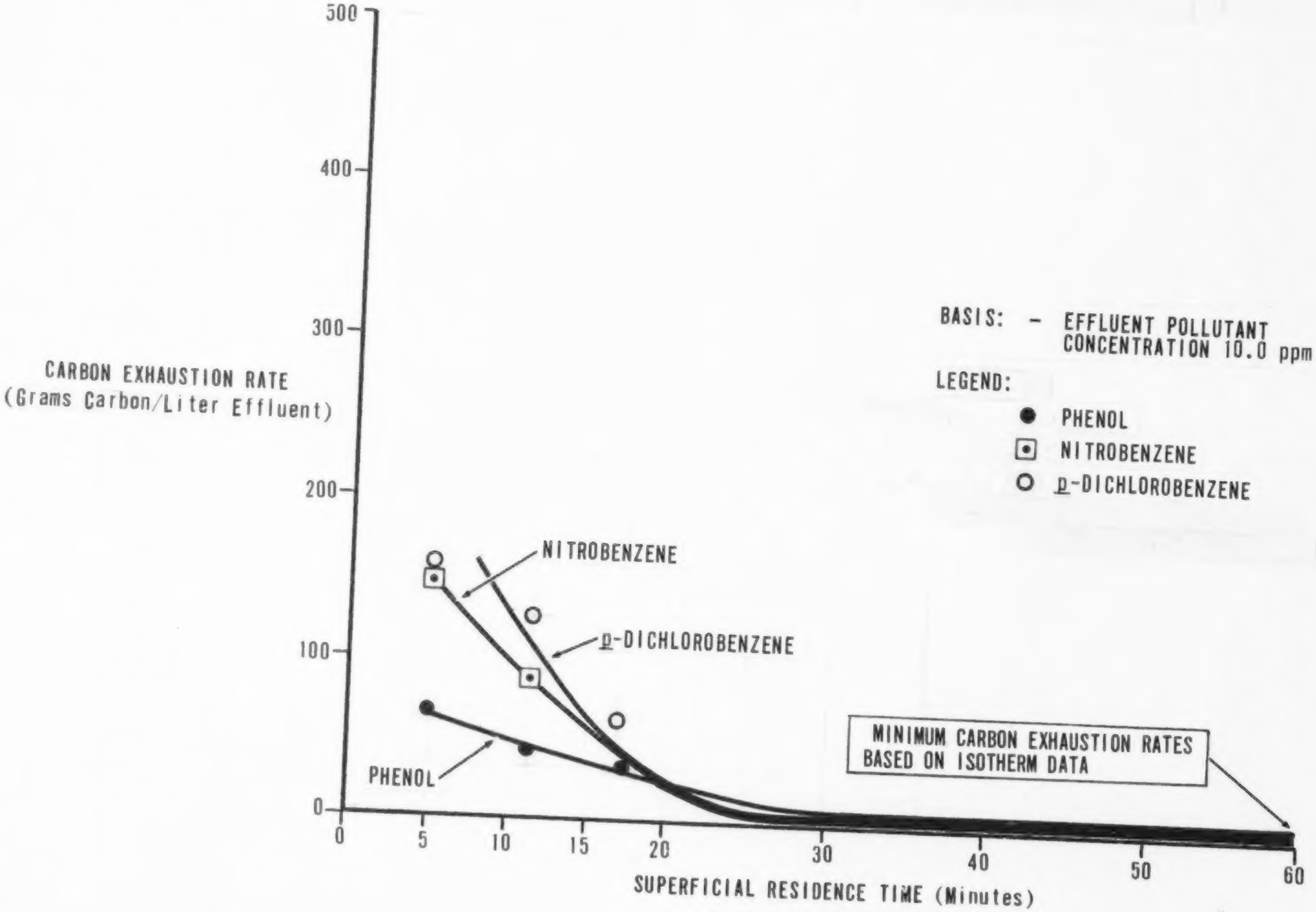

Figure 32. Carbon exhaustion rate vs. superficial residence time - effluent concentration 10.0 ppm.

diminishing return for long residence times. As the curve becomes flat, there is little advantage in increasing adsorber volume to extend contact times. An operating point based on the criteria of low carbon utilization was selected based on the controlling organic, phenol. Operating at a residence time greater than 34 minutes was not considered productive, since the exhaustion rate would not improve significantly. At the point selected, the carbon exhaustion rate is approximately 8.4 kg (18.5 pounds) of carbon per 1,000 liter of influent. Although shorter residence times would lower the capital investment, especially for the efficient pulsed bed unit, the effect on total costs is not great and therefore shorter times were not studied in detail.

The efficiency of an adsorption column is relatively insensitive to liquid loading rate (2). A rate of 210 liters per minute/square meter (5 gpm per square foot) was used for design purposes. This is at the low end of currently accepted industrial practice (10), but is higher than the value used in the laboratory tests. The design rate was based on more recent information than that used to establish the laboratory rate. This rate should insure that bed expansion will not take place. A 3.0 m (10 ft) diameter column was required for the design influent rate of 1,130 liters per minute. For this diameter column, and the specified residence time of 34 minutes, a column height of approximately 7.6 meters (25 feet) with a 6.9 meter (23 foot) bed depth was calculated. This column allows for a 10 percent freeboard and up to 30 percent additional capacity to accommodate the wastewater produced by the regeneration system.

Regeneration System:

A multiple hearth furnace was selected for this design. The required furnace capacity was determined from the carbon exhaustion rate of the adsorption column. An allowance of 40 percent was utilized to account for downtime and other contingencies in specifying the furnace size (11). Current data indicates that the furnace hearth area can be established using 0.01 square meters per kg (1 square foot per 40 pounds) of carbon regeneration per day (11). For the base case design, the carbon usage rate to reduce phenol to 1.0 ppm is 0.13 kg of carbon per liter (0.07 pounds of carbon per gallon) treated, using a 34 minute residence time. In order to treat 1130 liters per minute of influent, assuming a 33 percent recycle rate, approximately 18,600 kg (41,000 pounds) of carbon per day must be regenerated. Therefore, a furnace hearth area of about 130 square meters (1,400 square feet) is required. The furnace unit is equipped with an afterburner and scrubber as part of the installation to insure that exhaust gases meet acceptable standards.

Carbon Transport:

Spent carbon discharged from the adsorption column is carried in a slurry to a spent carbon bin. The bin provides a surge capacity in the system in the event of furnace downtime. The spent carbon is transported from the spent carbon bin to the regenerated furnace by a dewatering screw which simultaneously removes approximately 50 percent of the water content.

EPA-287 (Cin.)
(4-76)

Regenerated carbon is dumped into a quench tank for cooling. The slurry is then transported to one of three regenerated carbon wash tanks. In the tanks, the carbon is washed, and the fines pass out with the wash water. These solids are ultimately removed by filtration and disposed as a plant sludge. The three tanks operate cyclically, one tank receiving from the regeneration furnace, one tank undergoing the one hour wash cycle, and one tank replenishing the carbon fill chamber.

Carbon attrition is assumed to be 10 percent of the regeneration rate. Because of the quantity involved, the fresh carbon is delivered pneumatically from a storage silo into make-up carbon wash tanks. The fresh carbon is washed for one hour to remove fine particles and dirt. Two tanks operate cyclically, one washing, while one delivers to the carbon fill chamber. The carbon fill chamber, which provides a surge capacity in the system for regenerated carbon, delivers the carbon slurry to the adsorption column using gravity feed.

RESIN ADSORPTION

Resin adsorption of organic contaminants from an industrial wastewater is technically feasible. Aromatic compounds, such as the priority pollutants considered, are currently removed commercially by polymeric adsorption resins (3). Economic justification often rests on a combination of wastewater cleanup and recovery of specific compounds. This is particularly true of phenolic systems where toxicity and solubility together offer both a problem and an opportunity.

Comparison with carbon adsorption points up key differences which influence design choice and restrictions. The adsorptive resin material is very costly relative to carbon, but has a much longer regenerative life. Regeneration methods are limited to solvent wash.

Use of multiple columns, and cycling from adsorption to in situ regeneration, avoids resin handling expense and attrition losses. Resin life is such that the number of satisfactory regenerations may reach into the thousands (3). Thus no provision for routine resin handling is needed.

Effective solvent recovery is critical both to minimize expensive solvent losses and to provide a concentrated purge of pollutants from the system. In effect, the recovery system is a complex three-way separation, with purified solvent returning for reuse, concentrated pollutants being removed for disposal, and incidental water being returned to the wastewater influent for retreatment.

Choice of resin adsorption for a treatment system design offers selectivity of removal, possible recovery of pollutant materials, low energy consumption, minimized materials handling and durability of the resin matrix. However, resin generally offers a lower adsorptive capacity than activated carbon.

System Design

The process arrangement for this study is shown in Figure 33. There are three parallel fixed-bed adsorption columns with solvent regeneration of the resin and recovery of the solvent. This arrangement was selected based on an evaluation of regeneration and operation cycle times. It provides for a system of two on-stream columns and one column being regenerated at all times during normal operations. Continuous or near continuous flow of wastewater is desirable to minimize equipment size.

This study did not use a series arrangement since the superficial velocity limitations would have then required a larger diameter column. The sharp front of the breakthrough curve did not indicate operational advantage. Table 13 presents the base case equipment list.

The design superficial flow rate of 126 liters per minute per square meter (3 gpm per square foot) and bed depth of 1.8 meters (6 feet) are based on normal commercial practice. Although this flow rate is higher for this study than for the laboratory tests, the resin manufacturer indicates that equivalent or greater removal efficiency is expected at the higher flow rates (9). Thus, using laboratory data results in a conservative removal efficiency for the design study.

A column adsorption period of 4 to 5 hours was calculated. Thus with a three column system, two adsorbing and one regeneration, there would be a change of one column approximately every two hours. This two hour off-line period is sufficient for regeneration at reasonable solvent flow rates. A solvent flow period of one-half of the available regeneration time would call for a flow of about 230 liters per minute (60 gpm) in order to provide two bed volumes of solvent per regeneration, as recommended by the resin supplier.

At the beginning of regeneration of any one column, its water content is displaced by methanol solvent. Although some of the displaced water can be diverted to the wastewater system, a portion will inevitably mix with the methanol. This will consist of mixing with water at the solvent front. Also, that water entrapped in the resin pores will be subsequently displaced and mixed with methanol. For the purposes of this study, it is assumed that the total water mixed with solvent equals one bed volume per regeneration cycle.

STEAM STRIPPING

A system to accomplish the stripping of relatively low concentrations of organic priority pollutants from an industrial wastewater passes the aqueous stream to be treated counter-current with steam vapor in a contact column, permitting the stripping of the pollutant materials. The vapor is then condensed, forming two phases. One phase is aqueous, which is returned as reflux to the column and one phase is organic, which is made up of the concentrated, removed pollutants. Removed pollutants may be disposed of or recycled to the process.

The vapor upflow can be established either by direct input of steam or by indirect heat input to vaporize a portion of the treated wastewater. The indirect

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

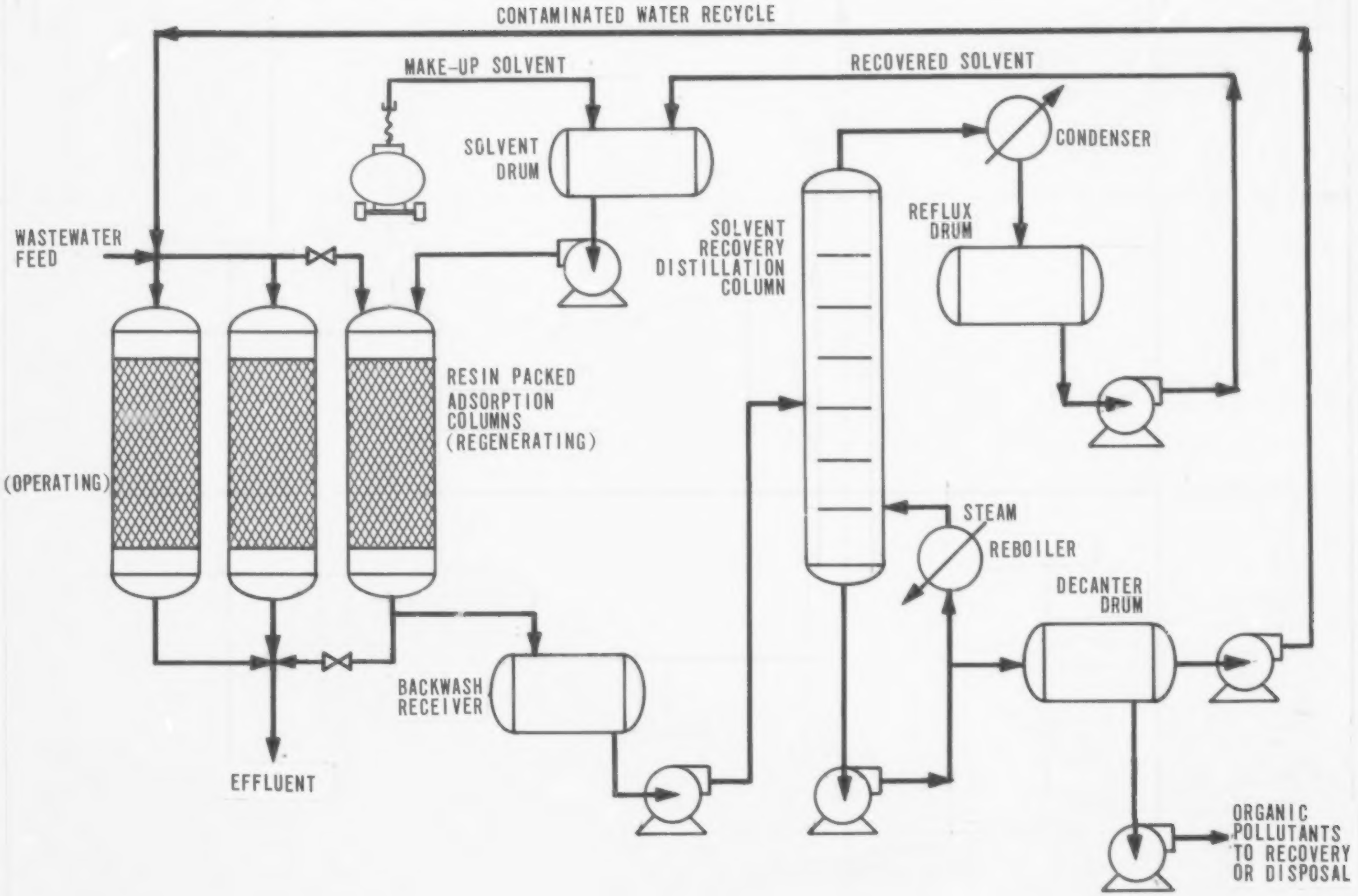
CONTAMINATED WATER RECYCLE
MAKE-UP SOLVENT
RECOVERED SOLVENT
SOLVENT DRUM
CONDENSER
REFLUX DRUM
WASTEWATER FEED
SOLVENT RECOVERY DISTILLATION COLUMN
RESIN PACKED ADSORPTION COLUMNS (REGENERATING)
(OPERATING)
STEAM
REBOILER
DECANTER DRUM
BACKWASH RECEIVER
EFFLUENT
ORGANIC POLLUTANTS TO RECOVERY OR DISPOSAL

Figure 33. Process flow - resin adsorption/regeneration/solvent system.

TABLE 13
EQUIPMENT LIST - RESIN ABSORPTION

ITEM	FUNCTION	NUMBER	DESCRIPTION
Column	Adsorption	3	2.4 m (8 ft.) diameter x 3.6 m (12ft.), resin-packed
Column	Distillation	1	1.2 m (4 ft.) diameter x 9.1m (30 ft.) incl. 6.1m (20 ft.) packing
Exchanger	Solvent recovery reboiler	1	18.6m^2 (200 ft.^{2}) shell and tube
Exchanger	Solvent recovery condensor	1	204.6m^2 (2,200ft.^{2}) shell and tube
Pump	Wastewater feed	2	1,130 l/min (300gpm), 138kPa (20psi), 7.5 kw (10hp) centrifugals
Pump	Solvent	2	230 l/min (60gpm), 69kPa (10psi), 1.5 kw (2hp) centrifugals
Pump	Solvent distillation feed	2	170 l/min (45gpm), 104kPa (15psi), 1.5 kw (2hp) centrifugal
Pump	Solvent reflux	2	230 l/min (60gpm), 138kPa (20psi), 2.2 kw (3hp) centrifugals
Pump	Bottoms	2	190 l/min (50gpm), 69kPa (10psi), 1.5 kw (2hp) centrifugals
Pump	Contaminated water recycle	2	4 l/min (1gpm), 138kPa (20psi), 0.7 kw (1hp) centrifugals
Drum	Solvent	1	Horizontal, low press. 104kPa (15psi), 66,200 l (17,500 gal.)
Drum	Backwash receiver	1	Horizontal, low press. 104kPa (15psi), 94,500 l (25,000 gal.)
Drum	Reflux	1	Horizontal, low press. 104kPa (15 psi), 15,100 l (4,000 gal.)
Drum	Decanter	1	Horizontal, low press. 104kPa (15psi), 4,200 l (1,100 gal.) with internal baffling

Basis: 1,130 l/min (300gpm) throughput, treatment to 1.0 ppm p-dichlorobenzene.

method entails incremental capital for reboiler surface, but avoids increasing the volume of wastewater discharged.

Since the major energy requirement in this system is the initial heat up of the feed, an economizer exchanger, to use the residual heat in the effluent bottom from the column, is clearly needed for any sizable stream flow. This also lowers the effluent temperature to meet possible discharge temperature restrictions. An exchange system optimizing heat recovery and exchanger surface costs would be a part of detailed design for a steam stripping unit.

System Design

Considering the fact that laboratory results roughly matched theoretical calculations, a material balance, shown in Table 14 was calculated for a higher degree of stripping, than experienced during the laboratory tests. This was based on published data and was done in order to determine which pollutants present impractical hurdles. This balance was used as the basis for a speculative design and economic evaluation. The calculation steps were as follows:

- Nitrobenzene was chosen as the design basis for this calculation.
- The effluent level of nitrobenzene was set at 1 ppm.
- The number of theoretical stages to accomplish the separation was based on a near minimum reflux ratio.
- The separations occurring simultaneously for the other four priority pollutants and aniline were calculated.
- Overall heat and material balances were determined and the column and exchanger sizes estimated.
- Where the calculated separation for phenol was not sufficient, the need for supplemental treatment was recognized.

Equilibrium coefficients, and activity coefficients, and solubilities in water were used in determining stripping feasibility and design. (Table 10)

The base case for which a steam stripping facility design was developed is shown in the process arrangement in Figure 34. An equipment list is presented in Table 15, indicating primary sizes for the process equipment.

The general design bases of flow and influent concentration and composition apply, except that the design did not include removal of phenol to the 1.0 ppm level. The difficulty in stripping phenolic compounds is generally recognized (12) and was confirmed by the laboratory tests and material balance calculations based on the thermodynamic properties of phenol. The poor removal of aniline is also predictable. The poor removal of dinitrotoluene in the laboratory tests was unexpected.

TABLE 14.
STEAM STRIPPING DESIGN MATERIAL BALANCE

COMPONENT	FEED	BOTTOMS	DISTILLATE	
	(ppm)	(ppm)	(ppm)	(ppm Parts Feed)
Chlorobenzene	8.8	Trace	20,600	8.8
p-Dichlorobenzene	36.4	Trace	85,200	36.4
Nitrobenzene	166	1	386,000	165
Aniline	1,329	1,213	272,000	116
Phenol	30.8	30.55	585	0.25
Dinitrotoluene	7.9	.01	18,500	7.89
Other organics (estimated)	421	328	218,000	93
TOTAL	2,000	1,573	1,000,000	427

Basis:
1. Reflux equals 10 percent of feed
2. 13 theroretical plates

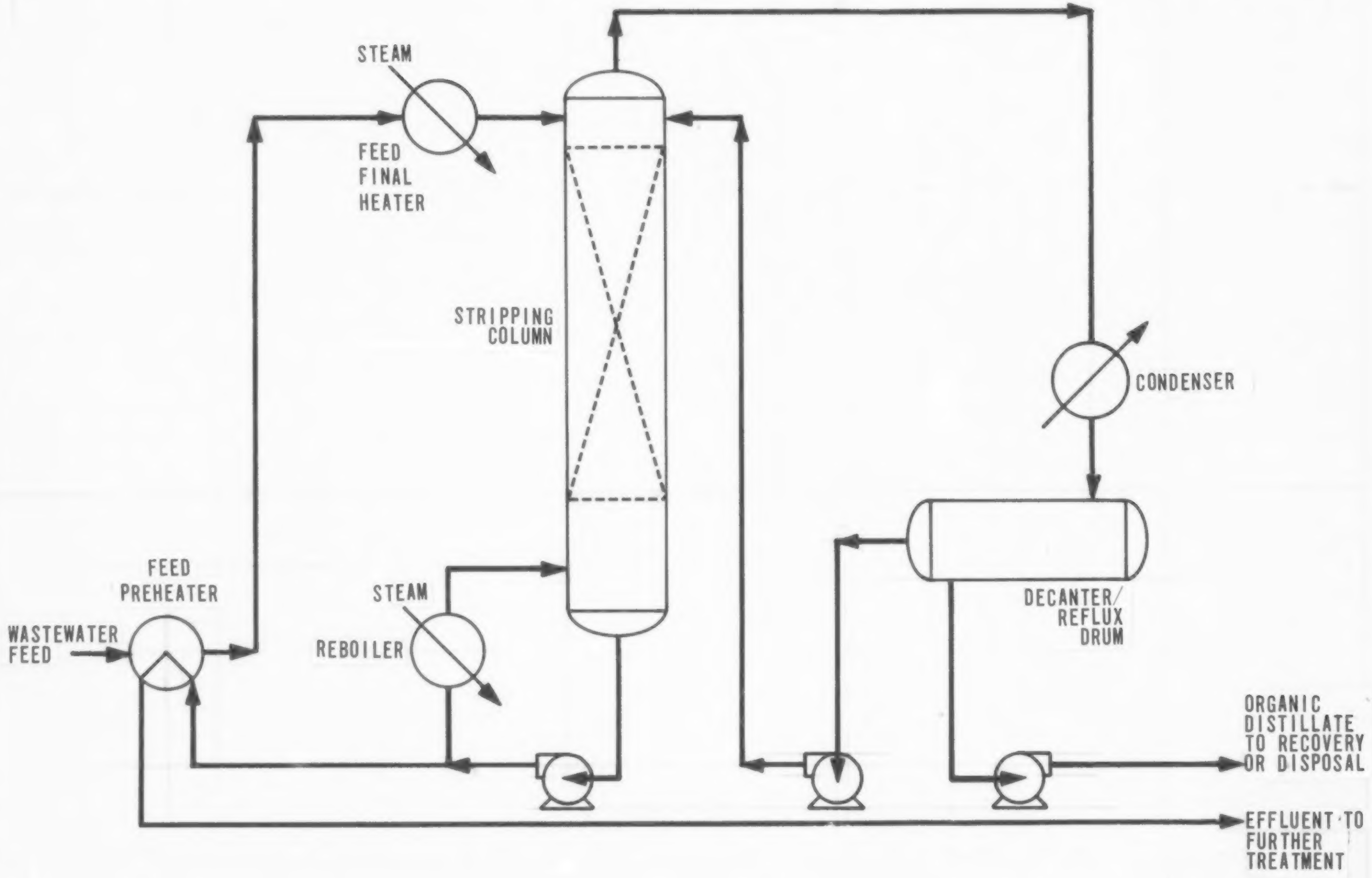
STEAM
FEED FINAL HEATER
STRIPPING COLUMN
CONDENSER
FEED PREHEATER
WASTEWATER FEED
STEAM
REBOILER
DECANTER/ REFLUX DRUM
ORGANIC DISTILLATE TO RECOVERY OR DISPOSAL
EFFLUENT TO FURTHER TREATMENT

Figure 34. Process flow - steam stripping system.

TABLE 15
EQUIPMENT LIST - STEAM STRIPPING

ITEM	FUNCTION	NUMBER	DESCRIPTION
Column	Stripper	1	1.1m (3.5 ft.) diam. x 6.9m (26 ft.), with 6.1m (20 ft.) grid packing
Exchanger	Feed water preheater	1	247m^2 (2,650 ft.^{2}) titanium plate exchanger
Exchanger	Feed water final heater	1	5.6 m^2 (60 ft.^{2}) shell and tube
Exchanger	Reboiler	1	18.6 m^2 (200 ft.^{2}) shell and tube
Exchanger	Condenser	1	115.3 m^2 (1,240 ft.^{2}) shell and tube
Pump	Bottoms wastewater	2	1320 l/min (350 gpm), 7.5 kw (10hp) centrifugal
Pump	Reflux	2	110 l/min (30 gpm), 0.7 kw (1 hp) centrifugal
Pump	Organic distillate	2	4 l/min (1 gpm), 0.7 kw (1 hp) centrifugal
Drum	Decanter/reflux	1	Horizontal, low pressure 2 atm (104 kPa), 18,900 l (5,000 gal.)

Basis: 1,130 l/min (300gpm) throughput, treatment to 1.0 ppm nitrobenzene.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The design studied is judged to represent the practical limit for the steam stripping system. Thus steam stripping did not perform as well as the two adsorption processes evaluated. Within this constraint, a 1,130 liters per minute atmospheric treatment unit can be described which removes nitrobenzene to the level of 1.0 ppm, and priority pollutants other than phenol (and possibly dinitrotoluene) to substantially lower levels. About thirteen theoretical stages are required with an aqueous reflux of about 10 percent of the feed rate. The resulting column was estimated to be 1.1 meter (3.5 feet) in diameter.

The overhead vapor would be condensed to form two phases and would be separated and decanted. The organic phase containing the total net organic pollutants removed from the wastewater would be routed to disposal. The aqueous phase would be refluxed and combined with the liquid feed to become the total down-flow liquid. The phase separation of the condensate may be difficult and a decanter/reflux drum would be a minimum requirement. The presence of emulsions or dispersed phases may introduce additional separation problems.

The organic distillate phase is a relatively concentrated mixture of the organic pollutants removed from the wastewater. Since these are the products and byproducts of the production units which generate the wastewater this mixed stream could possibly be returned to the process.

Total heat exchanger area required to raise the incoming water to its normal boiling point and to create the stripping vapor flow was estimated to be in the order of 372 square meters (4,000 square feet). Since significant heat is available in the effluent water leaving the column at 100°C, heat recovery is practical. An economizer heat exchanger between the cold feed and hot effluent was included in the exchanger area. Although stripping vapor could be generated by direct steam input, a bottoms reboiler was used to minimize water addition in the contaminated effluent.

EPA-287 (Cin.)
(4-76)

SECTION 7

ECONOMICS

An economic study was made for the three treatment technology designs discussed in Section 6. The following was assumed in order to provide common bases for comparison of treatment costs:

- Costs are for a developed Gulf Coast site with effluent and necessary utilities delivered to the treatment plant.
- Carbon steel construction is used throughout.
- Any required equalization or filtration already exists as part of the current plant treatment facilities.

In addition to economic evaluations for the base design case of Section 6, the effect on costs of volumetric flow rate and treatment to higher and lower effluent levels were considered.

The effect of different influent concentrations to the treatment system was beyond the scope of the tests. The probable effects are discussed for each technology and as a basis for evaluation of combination technologies.

CARBON ADSORPTION

Factors affecting economics are pollutant level in the influent, desired treatment level and flow rate.

Cost factors for the base case described in Section 6, including investment, operating cost, amortization, interest and taxes are tabulated in Table 16. These costs amount to about $2.38 per 1,000 liters of water treated. It should be noted that adsorption column costs represent about 25 percent of the total investment for the base case.

Figures 35 through 37 indicate the capital and treatment costs for various flow rates and treatment levels other than 1 ppm for the most difficult-to-remove priority pollutant, phenol. In developing the economics, the assumption was made that higher flow rates could be handled most easily by paralleling adsorption columns. Thus, for rates other than the base case rate, a straight line investment cost relationship was used for the adsorption columns. For the regeneration system costs, equipment sizes were assumed to increase directly with flow. Costs were considered to vary with size to the 0.7 power, as is typical for this type of equipment.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 16.
TREATMENT COSTS FOR CARBON ADSORPTION

Basis: 1,130 l/min (300 gpm) treatment to 1 ppm phenol.

Investment $ 1,775,000

Working Capital $85,000

					Treatment Costs	
Materials Cost					$/yr	$/1,000 l
Streams	kg/yr	$/unit				
Carbon Replacement	679,500	0.79			537,500	
				Subtotal	537,500	0.90
Processing Cost						
Labor Directed:						
Direct Labor					110,000	
Supervision			@10% D.L.		11,000	
Plant Overhead			@100%D.L.		110,000	
				Subtotal	231,000	0.39
Investment Directed:						
Amortization Cost*					340,000	
Taxes & Insurance			@2% Inv.		35,500	
Maintenance			@4% Inv.		70,000	
Supplies					18,000	
				Subtotal	463,500	0.78
Throughput Directed:						
Fuel			@$0.30/Therm		145,500	
Other Utilities					37,000	
				Subtotal	182,500	0.31
Total Treatment Cost					1,414,500	2.38

*Based on 12 years and 15 percent interest.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

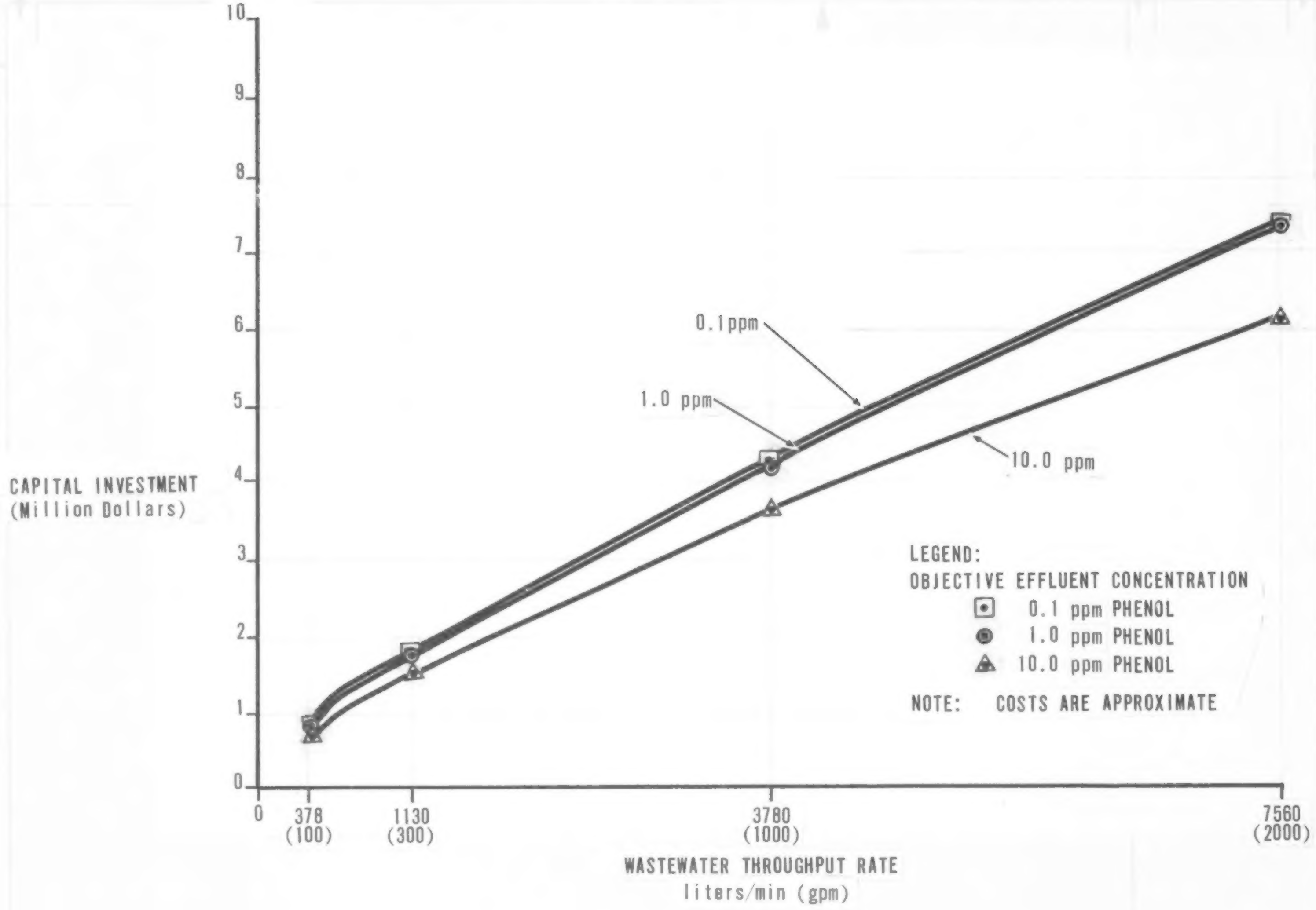

Figure 35. Capital investment vs. wastewater throughput rate - carbon adsorption.

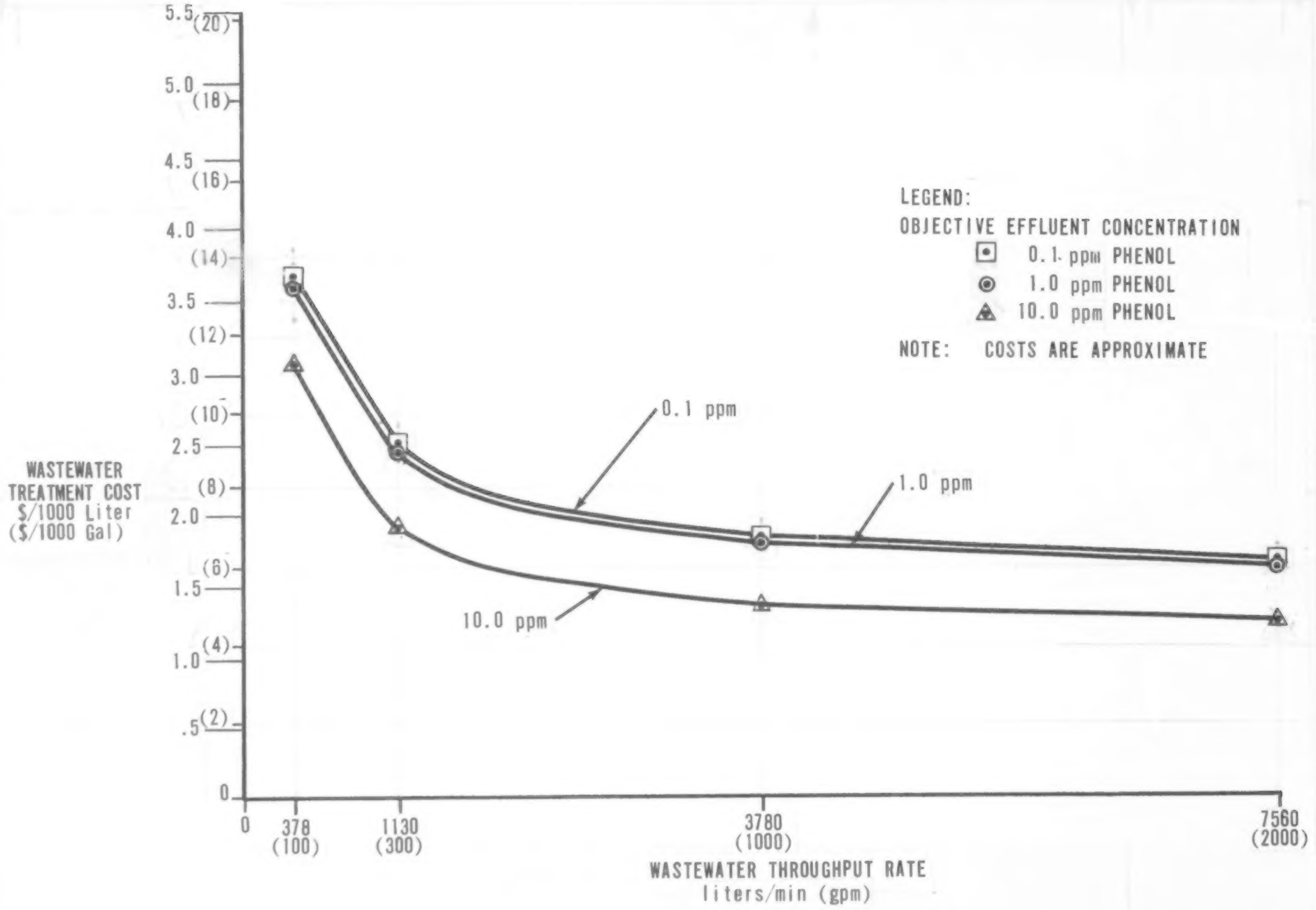

Figure 36. Carbon adsorption treatment cost vs. wastewater throughput rate.

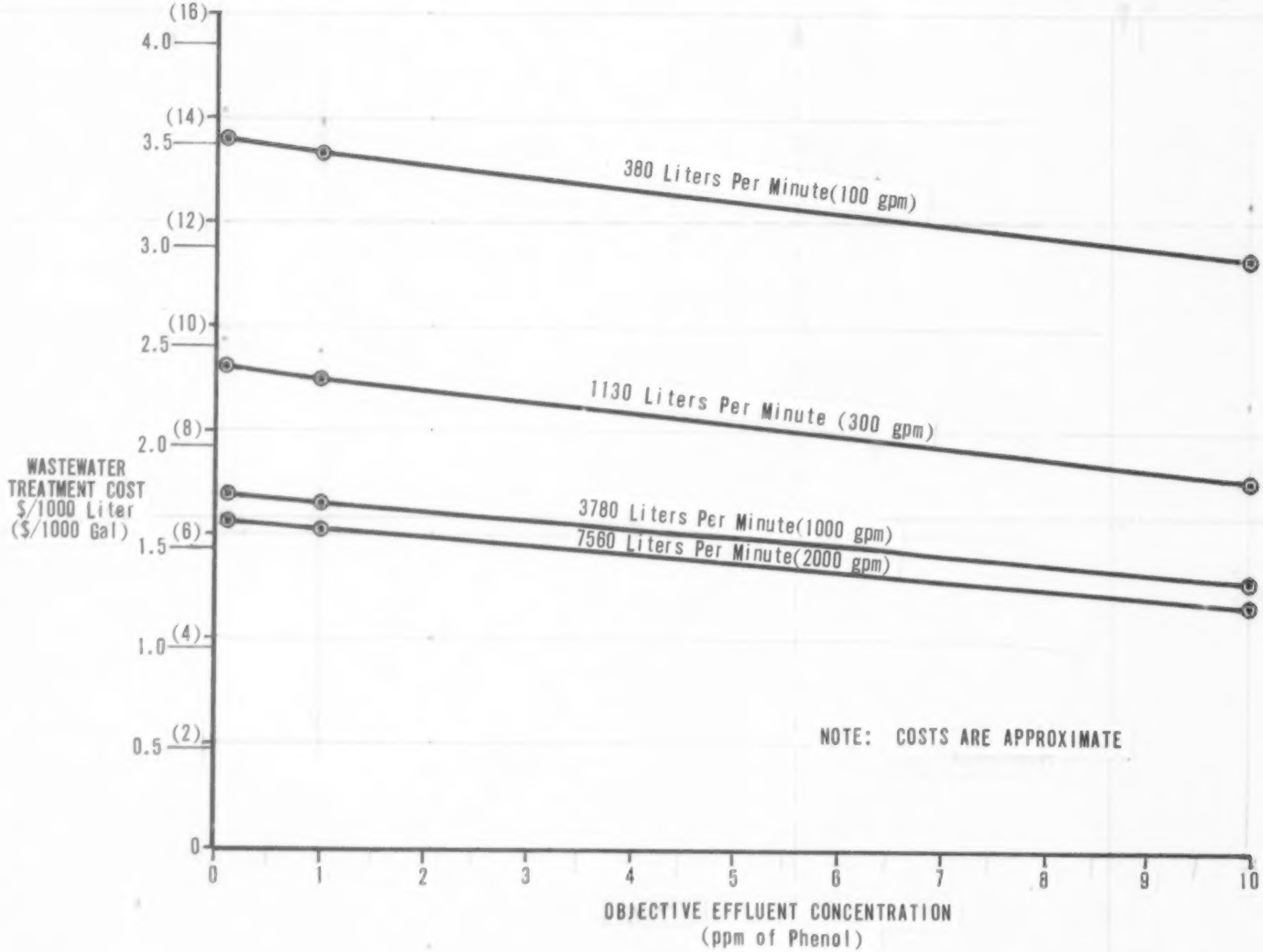

Figure 37. Carbon adsorption treatment cost vs. objective effluent concentration.

Treatment level has virtually no effect on the costs for the adsorption portion of the system. Size of the regeneration system and carbon loss would be proportional to the total amount of pollutant removed.

The operating costs for the total treatment facility were developed partly from guidelines found in the "Process Design Manual for Carbon Adsorption" (11). Individual cost items were modified to account for plant location, operating conditions and first quarter 1980 prices and wages. Labor requirements were estimated based on similar industrial operations.

It is important to note the impact of carbon usage on operating costs. One time carbon use is unacceptable; however, the 10 percent loss assumed in this study is also quite significant and contributes about $0.90 per 1,000 liter to the base case treatment costs.

It was not possible to predict accurately the impact of influent concentration on operating costs. To speculate on the effect of a pretreatment, which would remove some of the contaminants, a simplistic evaluation was made. It was assumed that influent concentrations were uniformly reduced and the isotherm data obtained in the laboratory tests still applied. On this basis, a six fold reduction in influent concentration was needed before operating costs for the base case flow rate were reduced 50 percent. These results are very rough and simply indicate that economic advantages may exist if influent concentrations can be significantly lowered. Additional data would be needed to accurately determine actual carbon performance for a pretreated waste.

If steam stripping were a pretreatment, the concentration of phenol would probably be essentially unaffected as other contaminant levels are reduced. There is an indication, based on adsorption background information, that the carbon isotherm for this least adsorbed material would remain relatively unaffected as the other materials are reduced. Treatment costs by carbon adsorption therefore should not change following a steam stripping pretreatment.

RESIN ADSORPTION

In addition to factors such as pollutant level in influent, desired treatment level, flow rate, and resin life, other important considerations include solvent costs and disposition of removed pollutants. Methanol used in the base case design study as a low priced solvent. It was assumed that there would be no disposal costs for removed pollutants (recycle to process or to existing fuel system).

Costs for the base case, including investment, operating costs, amortization, interest and taxes are tabulated in Table 17. These costs amount to $2.86 per 1,000 liter of water treated.

Figure 38 shows the variation of capital investment with wastewater throughput. Figures 39 and 40 include the operating costs for flow rates other than 1,130 liters per minute and treatment levels other than 1 ppm of p-dichlorobenzene as the breakthrough component. Since equipment costs do not vary in direct

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 17.
TREATMENT COSTS FOR RESIN ADSORPTION

Basis: 1,130 l/min (300 gpm) treatment to 1 ppm p-dichlorobenzene.

Investment $1,700,000

Working Capital $ 370,000

				Treatment Costs	
Materials Cost				$/yr	$/1,000 l
Streams	units/yr	$/unit			
Resin Replacement	$28.3m^3$	8,833.92		250,000	
Royalty On Resin	$28.3m^3$	424.03		12,000	
Methanol	1,239,840 l	0.17		213,000	
			Subtotal	475,000	0.80
Processing Cost					
Labor Directed:					
Direct Labor				105,000	
Supervision 10% Direct Labor				10,000	
Plant Overhead 100% Direct Labor				105,000	
			Subtotal	220,000	0.37
Investment Directed:					
Amortization Cost*				351,000	
Taxes & Insurance		@2% Inv.		34,000	
Maintenance		@4% Inv.		68,000	
Supplies		@1% Inv.		17,000	
			Subtotal	470,000	0.79
Throughput Directed:					
Steam $0.77/100 kg				475,000	
Other Utilities				51,000	
			Subtotal	536,000	0.90
Total Treatment Cost				1,701,000	2.86

*Based on 12 years and 15 percent interst.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

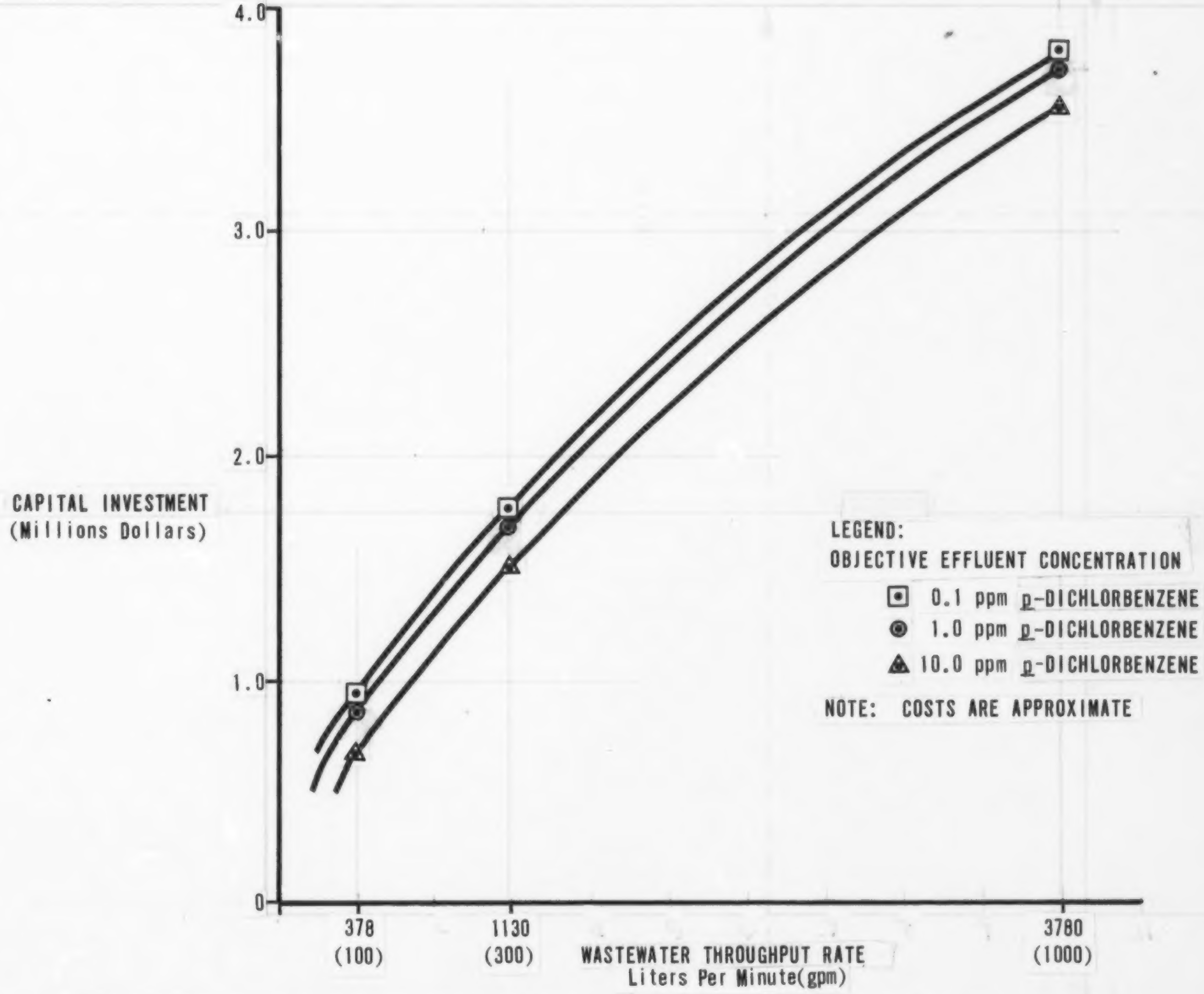

Figure 38. Capital investment vs. wastewater throughput rate - resin adsorption.

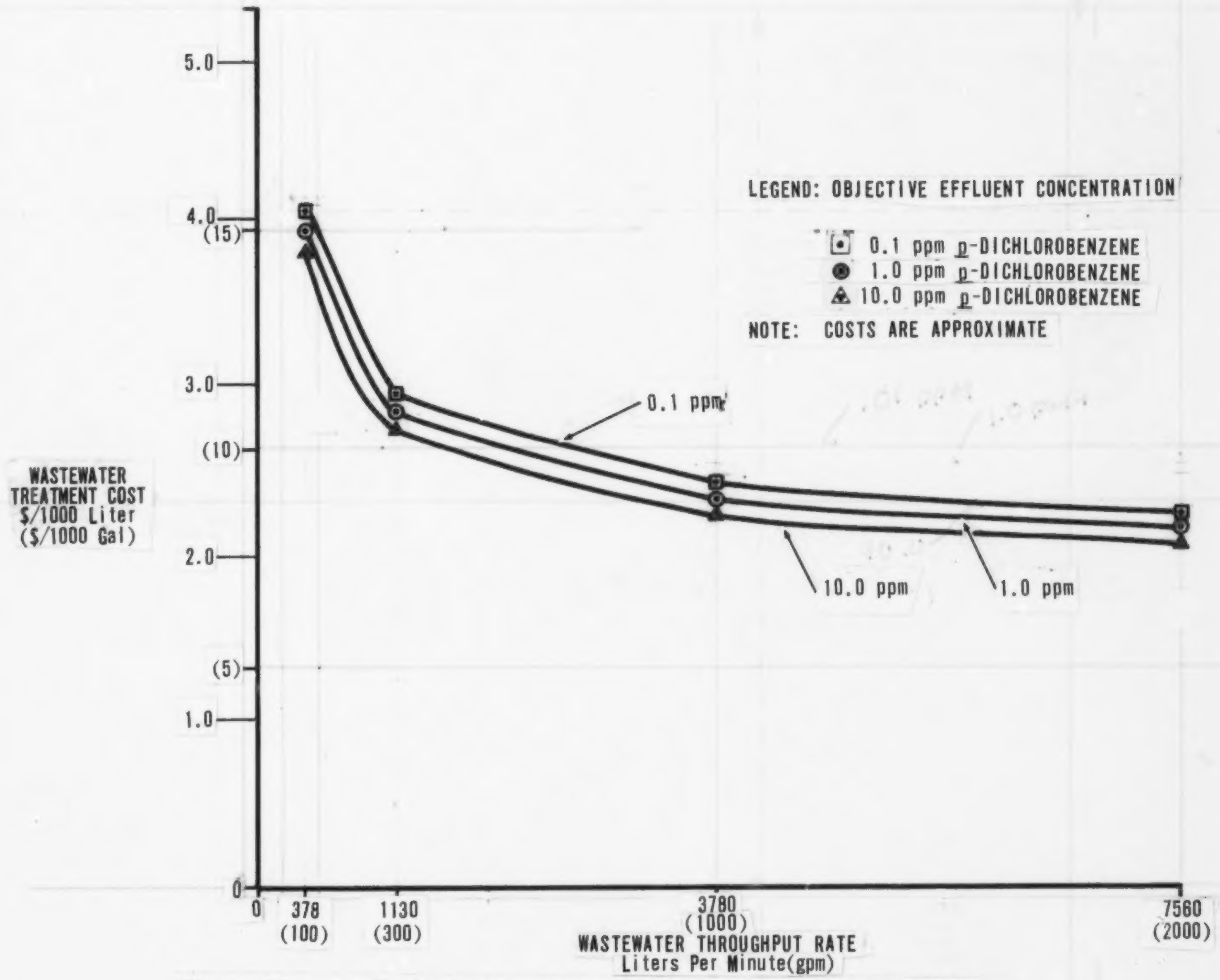

Figure 39. Resin treatment cost vs. wastewater throughput rate.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
5/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

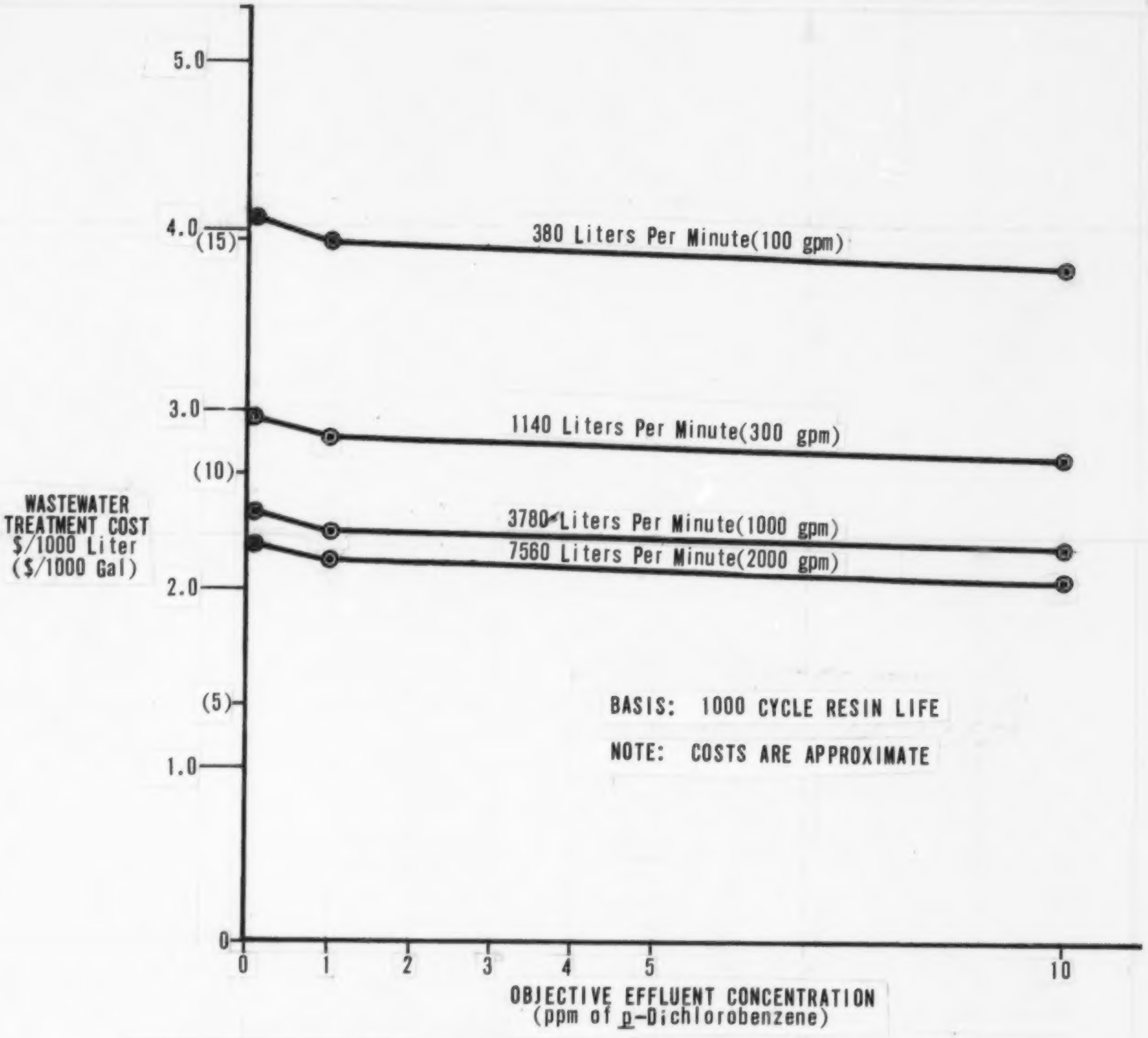

Figure 40. Resin treatment cost vs. objective effluent concentration.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

proportion to size, costs per unit volume will decrease with flow rate increases. Treatment level affects the total volume which may be treated before regeneration. A change in throughput volume before regeneration results in a small impact on regeneration size requirements and solvent and resin utilization.

Commercial applications point to useful resin life exceeding several hundred cycles over a period of years (3). This is an important consideration due to the high cost of resin. Resin life can be known only after lengthy testing. The effect of resin life on treatment costs is presented in Figure 41. The base case economics considers a resin life of 1,000 regenerations.

The effect of influent wastewater pollutant concentration on the cost of treatment is not easily evaluated. Qualitatively, treatment costs are reduced by lowering the influent concentrations of a fixed slate of pollutants. Various bases can be considered to estimate resin adsorption performance with reduced wastewater feed concentrations such as would exist by pretreatment. One basis is to assume that the resin bed is saturated at breakthrough, based on the TOC isotherm. Bed design for the reduced influent concentration would be based on saturation for a lower TOC value. This basically treats all of the pollutants as equivalent in the adsorption process, and may be optimistic. This was the approach taken, however, in evaluating combined treatment discussed later.

STEAM STRIPPING

Factors significant in the cost of treating wastewater by steam stripping include the type and level of pollutant in the influent, desired treatment level, flow rate and the cost of energy.

Treatment costs are as summarized in Table 18, for a base throughput of 1,130 liters per minute. Variation of treatment cost and investment with throughput rate are shown in Figures 42 and 43, respectively. It must be remembered that application of steam stripping as a total treatment is limited to systems without phenol (and some other pollutants) since phenol is not expected to strip. Otherwise, its application is limited to possible use as a pretreatment in a combined treatment system.

Steam consumption, necessary to provide heat input for stripping vapor and to complete heating of the feed, is the most significant design variable affecting the economics of a system using steam stripping. Reflux ratio and heat recovery are areas calling for optimization at the design stage.

COMBINED TECHNOLOGY

Based on the results of studies for the individual technologies, certain conclusions can be drawn regarding combination treatment systems. There are no advantages seen for the use of the adsorption systems in combination. Neither carbon or resin adsorption costs are sensitive to treatment level and each technology can treat to very low levels.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

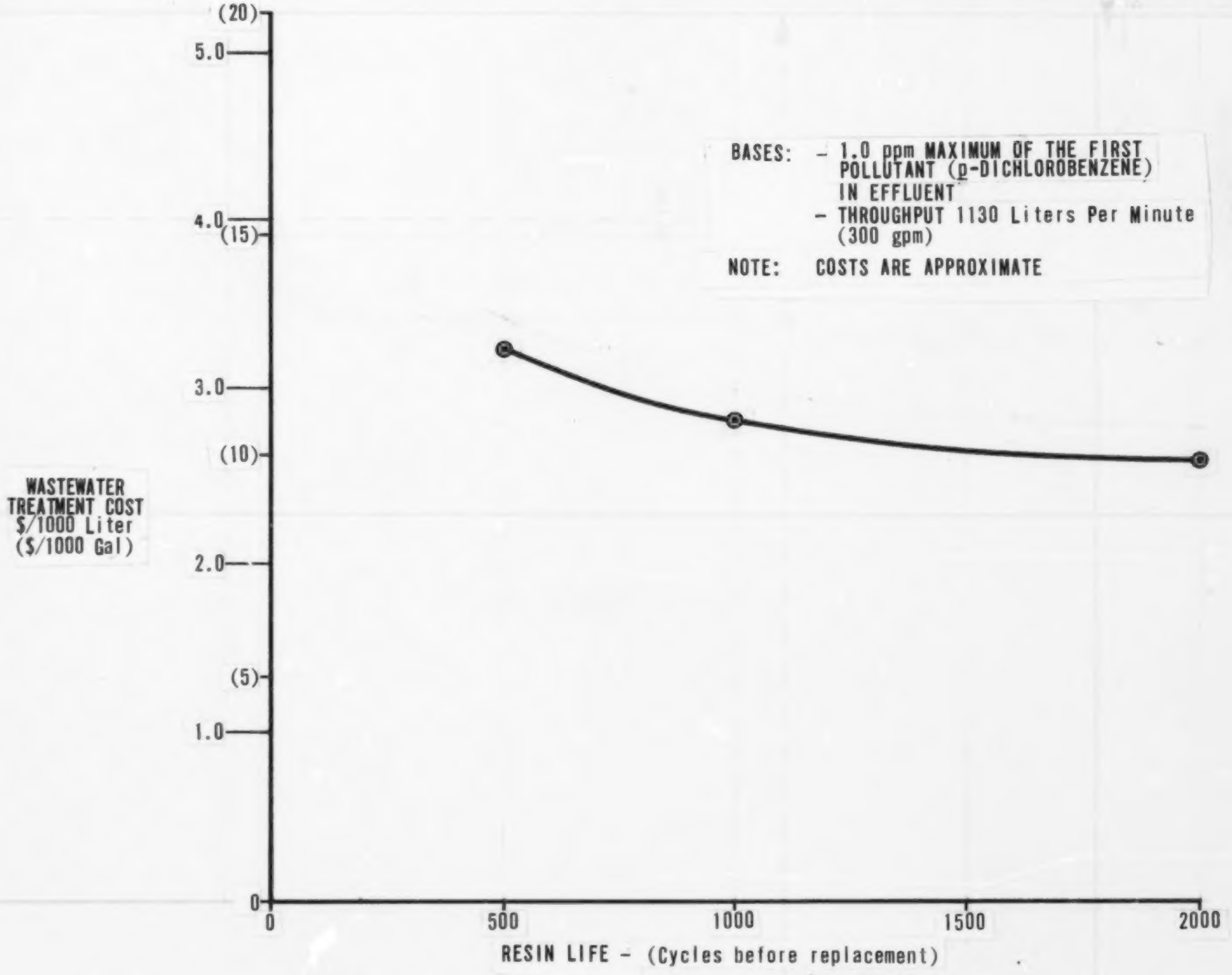

Figure 41. Resin treatment cost vs. resin life.

EPA-287 (Cin.) (4-76)

TABLE 18.
TREATMENT COSTS FOR STEAM STRIPPING

Basis: 1,130 l/min (300 gpm) treatment to 1.0 ppm of nitrobenzene

Investment: $ 1,000,000

Working Capital $ 100,000

			Treatment Costs	
			$/yr	$/1,000 l
Processing Cost				
Labor Directed;				
Direct Labor			53,000	
Supervision	10% D.L.		5,000	
Plant Overhead	100% D.L.		53,000	
		Subtotal	111,000	0.19
Investment Directed:				
Amortization Cost*			200,00	
Taxes & Insurance	@ 2% Inv.		20,000	
Maintenance	@ 4% Inv.		40,000	
Supplies	@ 1% Inv.		10,000	
		Subtotal	270,000	0.45
Throughput Directed:				
Steam	0.77/100 kg		613,000	
Other Utilities			80,000	
		Subtotal	693,000	1.16
Total Treatment Cost			1,074,000	1.80

*Based on 12 years and 15 percent interest.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

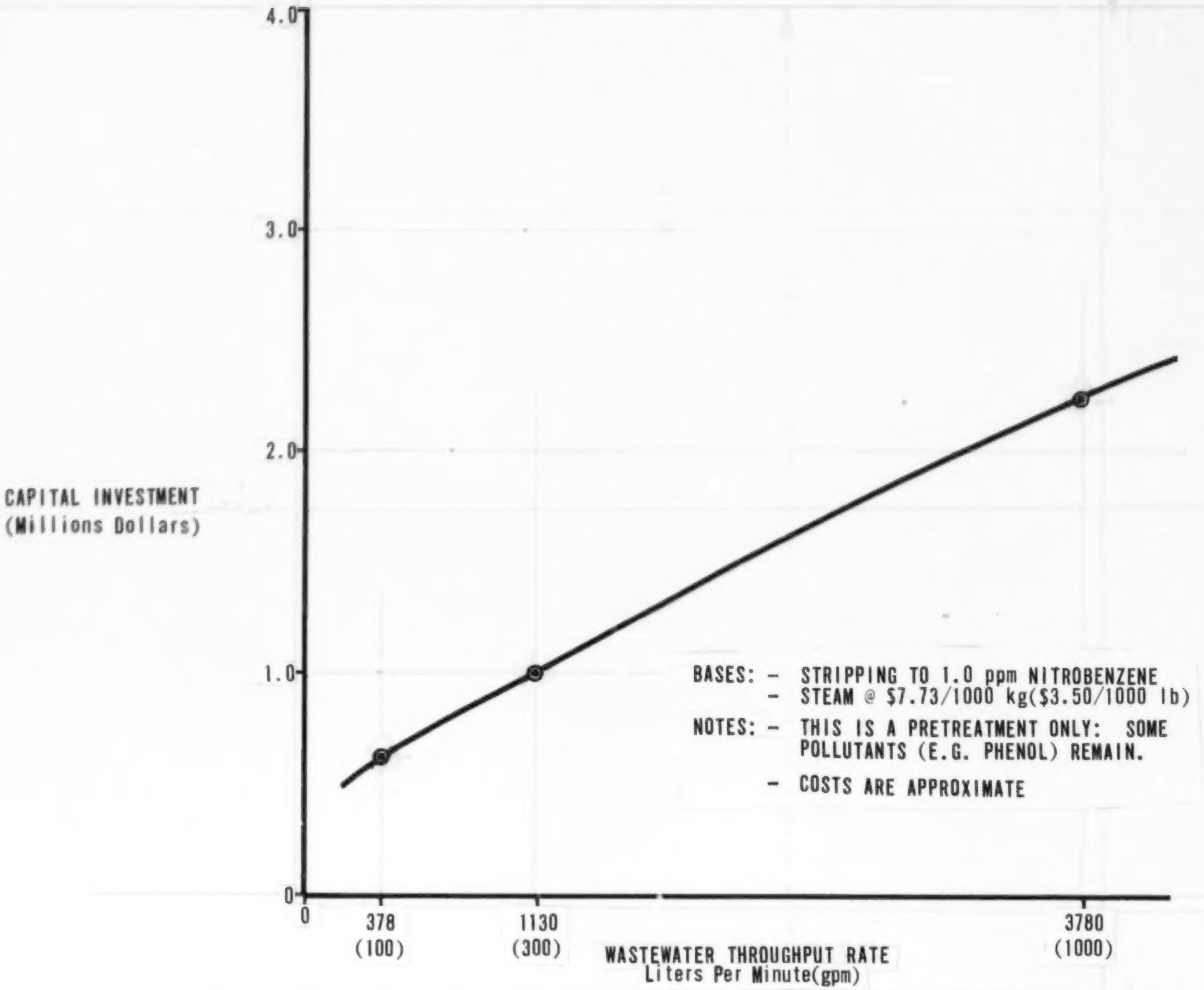

Figure 42. Capital investment vs. wastewater throughput rate - steam stripping.

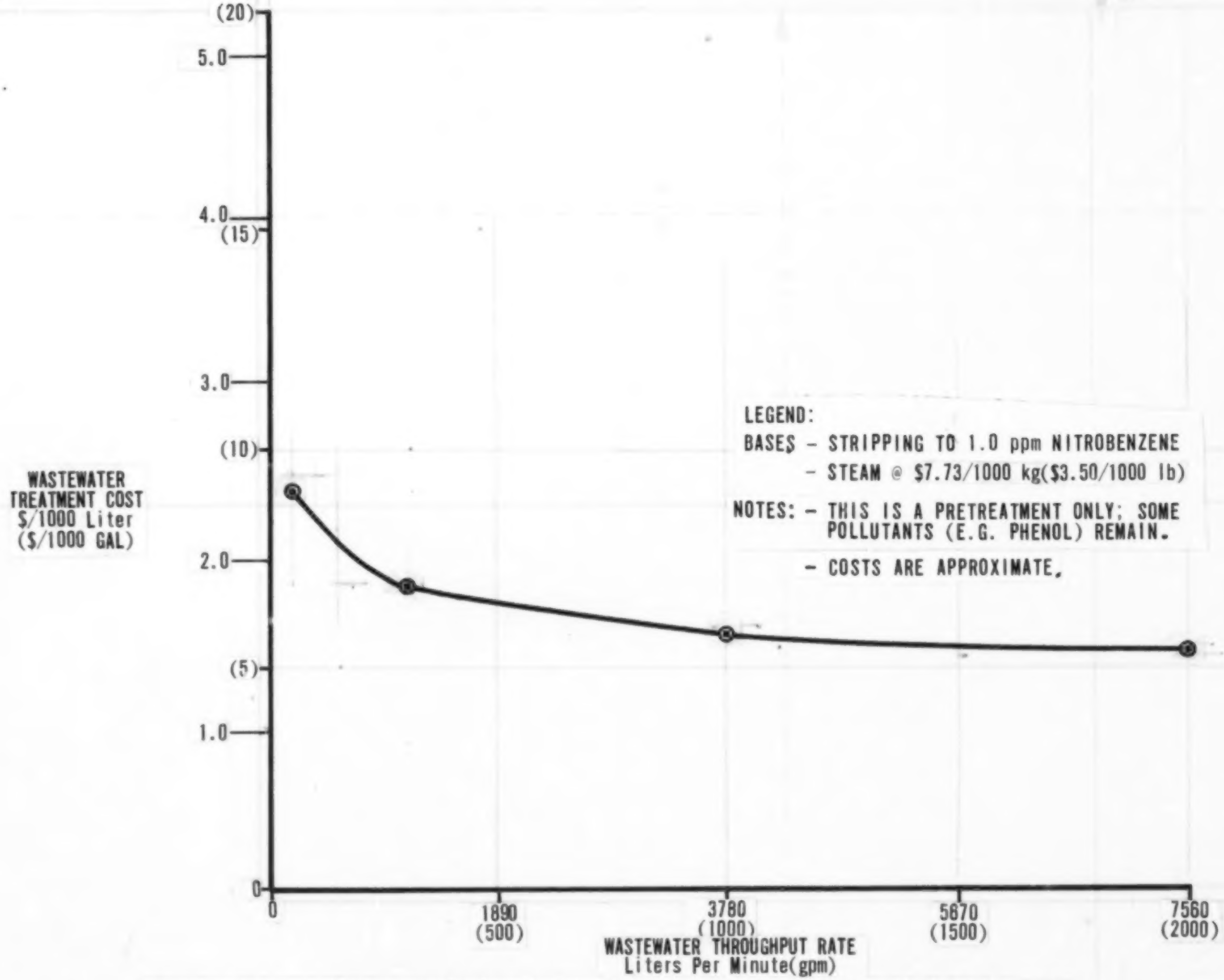

Figure 43. Steam stripping treatment cost vs. wastewater throughput rate.

Steam stripping as a pretreatment, in conjunction with either of the adsorption processes, also appears to offer no economic advantages. Phenol is the controlling pollutant for carbon adsorption, but the phenol level is essentially unchanged based on a steam stripping pretreatment. Furthermore, carbon's capacity for phenol is not expected to improve significantly when other pollutants are lowered due to pretreatment (private communications, ICI Americas). On this basis, steam stripping, plus carbon adsorption, would be less cost effective than carbon adsorption alone. Even an unlikely reduction of 50 percent in the costs of carbon treatment would not make combined steam stripping and carbon adsorption as cost effective as carbon adsorption alone.

The combination of steam stripping and resin adsorption was also evaluated in some detail. Estimated operating costs for this combination are shown in Table 19. Indications are that resin does not particularly distinguish between single ring aromatics (private communications, Rohm and Haas). TOC was used as an indication of the priority pollutants present. Also, resin was considered essentially saturated at breakthrough. Based on resin TOC isotherm data and an expected TOC after steam stripping, resin holding capacity at saturation and resin bed size were estimated. Costs for the resin treatment after steam stripping were still high, as indicated in Table 19. Based on these results, combination treatment would be far more expensive than resin treatment alone.

Less extensive pretreatment could improve stripping costs, but the combined costs for steam stripping plus either carbon or resin adsorption would remain high.

TABLE 19
TREATMENT COSTS FOR COMBINED TREATMENT

Basis: 1,130 l/min (300 gpm) to 1 ppm nitrobenzene pretreatment and 1 ppm phenol final treatment.

		Stripping Pre-Treatment	Resin Final Treatment	TOTAL	
Investment $		1,000,000	1,400,000	2,400,000	
Working Capital $		100,000	357,000		
		Treatment Costs			
Materials Cost		$/yr	$/yr	$/yr	$/1000 l
Streams	$/unit				
Resin Replacement	$8833.92/m^3	-	162,000		
Royalty On Resin	$424.03/m^3	-	8,000		
Methanol	$0.17/l	-	138,000		
	Subtotal	-	308,000	308,000	0.52
Processing Cost					
Labor Directed:					
Direct Labor		53,000	105,000		
Supervision	@10% D.L.	5,000	10,000		
Plant Overhead	@100% D.L.	53,000	105,000		
	Subtotal	111,000	220,000	331,000	0.55
Investment Directed:					
Amortization Costs*		200,000	312,00		
Taxes & Insurance	@2% Inv.	20,000	28,000		
Maintenance	@4% Inv.	40,000	56,000		
Supplies	@1% Inv.	10,000	14,000		
	Subtotal	270,000	410,000	680,000	1.14
Throughput Directed:					
Steam	@0.77/100 kg	613,000	308,000		
Other Utilities		80,000	40,000		
	Subtotal	693,000	348,000	1,041,000	1.75
Total Treatment Cost		1,074,000	1,286,000	2,360,000	3.96

*Based on 12 years and 15 percent interest.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

REFERENCES

1. U. S. Environmental Protection Agency, Priority Pollutant Treatability Review (Contract 68-03-2579), July, 1978.

2. Rizzo, J. L. and Shepard, A. R., "Treating Industrial Wastewater with Activated Carbon", Chemical Engineering, January 3, 1977, pp 95-100.

3. Fox, C. R., "Plant Uses Prove Phenol Recovery with Resins", Hydrocarbon Processing, November, 1978.

4. B. Bickford et al. Preliminary Draft Report Master Scheme for the Analysis of Organic Compounds in Water, Part III: Experimental Development and Results, Contract No. 68-03-2704, Research Triangle Institute and Gulf South Research Institute for the U. S. Environmental Protection Agency, Athens, Georgia.

5. Bellar, T. A. and J. J. Lichtenberg, "Organics at Microgram-per-liter Levels by Gas Chromatography", J. American Water Works Assoc. 379-744, December 1974.

6. Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants, Environmental Monitoring and Support Laboratory EPA, Cincinnati, Ohio, April, 1977.

7. The Laboratory Evaluations of Granular Activated Carbons for Liquid Phase Applications, Technical Bulletin, Pittsburgh Activated Carbon Company, March 1966.

8. "Carbon Adsorption Handbook", Ed. by P. N. Cheremisinoff and F. Ellerbusch, Ann Arbor Science Publishers, Inc., 1978.

9. Laboratory Column Procedures for Testing Amberlite Polymeric Adsorbents, Technical Bulletin, Fluid Process Chemicals, Rohm and Haas Company, May, 1979.

10. Hutchis, R. A., "Liquid-phase Adsorption: Maximizing Performance", Chemical Engineering, February 25, 1980, pp 101-110.

11. U. S. Environmental Protection Agency, Process Design Manal for Carbon Adsorption, October, 1973.

12. Hwang, S. T. and Fahrenthold, P., Treatability of the Organic Priority Pollutants by Steam Stripping, Paper presented at AIChE Meeting, Boston, August, 1979.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BIBLIOGRAPHY

Constance, J. D., "'Six-tenths' Factor Gives Cost Change," *Power*, September, 1969, p 89.

Erskin, D. B. and Schuliger, W. G., "Activated Carbon Processes for Liquids," *Chemical Engineering Progress*, November, 1971, pp 41-44.

Fornwalt, H. J. and Hutchins, R. A., "Purifying Liquids with Activated Carbon," *Chemical Engineering*, May 9, 1966, pp 155-160.

Fox, C. R., "Removing Toxic Organics from Waste Water," *Chemical Engineering Progress*, August, 1979.

Gallant, R. W., *Physical Properties of Hydrocarbons*, Gulf Publishig Co., Vol. 2, p 132, 1970.

Gmehling, J., and Onken, U., *Vapor - Liquid Equilibrium Data Collection*, DECHEMAA Chemistry Data Series, 1977.

Hutchins, R. A., "Activated Carbon - Economic Factors in Granular Carbon Thermal Regeneration," *Chemical Engineering Progress*, November, 1973, pp 48-55.

Hutchins, R. A., "Activated Carbon Regeneration: Thermal Regeneration Costs," *Chemical Engineering Progress*, May, 1975, pp 80-86.

McCabe, W. L. and Smith, J. C., *Unit Operations of Chemical Engineering*, 2nd ed., McGraw-Hill.

Morrison, R. T. and Boyd, R. N., *Organic Chemistry*, 3rd ed., Allyn and Bacon, 1973, p 730.

Mulligan, T. J. and Fox, R. D., "Treatment of Industrial Wastewaters," *Chemical Engineering Deskbook*, October 18, 1976, pp 49-66.

Norton Chemical Process Products (U. S. Stoneware), Packed Towers.

Peel, R. G. and Benedek, A., "Attainment of Equilibrium in Activated Carbon Isotherm Studies," *Environmental Science and Technology*, January, 1980, pp 66-71.

Reid, R. C., Prausnitz, J. M. and Sherwood, T. K., *The Properties of Gases and Liquids*, 3rd ed., McGraw-Hill, 1977, pp 347-355.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Tsonopoulos, Constantine and Prausnitz, J. M., Activity Coefficients of Aromatic Solutes in Dilute Aqueous Solutions, Vol. 10, 593, 1971.

Weber, W. J., Physiochemical Processes for Water Quality Control, Wiley - Interscience, New York, 1972.

Zanitsch, R. H. and Lynch, R. T., "Selecting a Thermal Regeneration System for Activated Carbon," Chemical Engineering, January 2, 1978, pp 95-100.

—, Amberlite Ion Exchange Resins, Amber-hi-lites, Rohm and Haas Co., August, 1978.

—, Amberlite XAD-4, Technical Bulletin Fluid Process Chemicals, Rohm and Haas, Co., February, 1978.

—, Summary Bulletin, Amberlite Polymeric Adsorbents, Technical Bulletin Fluid Process Chemicals, Rohm and Haas Co., June, 1978.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

APPENDIX

LABORATORY DATA

This appendix is a compilation of laboratory data recorded to determine isotherms and breakthrough patterns which are depicted graphically in this study.

The following tables are included:

Equilibrium Concentrations of Effluent Constituents in Activated Carbon Isotherm Studies at pH 9	(Table 1A)
Equilibrium Concentrations of Effluent Constituents in Activated Carbon Isotherm Studies at pH 7	(Table 2A)
Equilibrium Concentrations of Effluent Constituents in Activated Carbon Isotherm Studies at pH 3	(Table 3A)
Virgin Carbon Used for 400° Thermal Regeneration Study	(Table 4A)
Thermal Regeneration, First Regeneration (400°C)	(Table 5A)
Thermal Regeneration, Second Regeneration (400°C)	(Table 6A)
Thermal Regeneration, Third Regeneration (400°C)	(Table 7A)
Thermal Regeneration, Fourth Regeneration (400°C)	(Table 8A)
Virgin Carbon Used for 800°C Thermal Regeneration Study	(Table 9A)
Thermal Regeneration at 800°C, First Regeneration	(Table 10A)
Virgin Carbon Used for Steam Regeneration Study	(Table 11A)
Steam Regeneration, First Regeneration	(Table 12A)
Steam Regeneration, Second Regeneration	(Table 13A)
Steam Regeneration, Third Regeneration	(Table 14A)
Steam Regeneration, Fourth Regeneration	(Table 15A)

6-1/2"
9-7/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Steam Regeneration, Fifth Regeneration (Table 16A)

Equilibrium Concentration of Effluent Constituents in XAD-4 Resin Isotherm Studies (Table 17A)

Virgin XAD-4 Resin Used for Regeneration Studies (Table 18A)

XAD-4 Regeneration, First Regeneration (Table 19A)

XAD-4 Regeneration, Second Regeneration (Table 20A)

XAD-4 Regeneration, Third Regeneration (Table 21A)

XAD-4 Regeneration, Fourth Regeneration (Table 22A)

XAD-4 Regeneration, Fifth Regeneration (Table 23A)

Initial Test Run After 3 Times Normal Solvent Preparation Wash (Table 24A)

6-1/2
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 1A
EQUILIBRIUM CONCENTRATIONS OF EFFLUENT CONSTITUENTS IN ACTIVATED CARBON ISOTHERM STUDIES AT pH 9 (ppm)

		ICI (HDC) Carbon(1)					ICI (S-51) Carbon(1)				
Constituent	Untreate Effluent	0.1	0.5	1.0	5.0	10.5	0.1	0.5	1.0	5.0	10.5
TOC	1,418	1,263	900	548	99	72	1,225	856	453	56	38
Chlorobenzene	8.8	3.3	0.70	0.09	0.01	0.004	3.56	0.66	0.035	0.0008	-
p-Dichlorobenzene	36.0	0.849	0.044	0.02	0.002	0.0003	0.607	0.050	0.016	0.0008	-
Nitrobenzene	166	63.0	7.63	1.79	0.019	0.001	70.6	9.16	0.878	0.009	0.001
Phenol	30.8	27.6	21.3	11.5	0.280	0.014	28.0	18.5	5.60	0.28	0.014
Dinitrotoluene	7.9	1.02	0.067	0.006	0.003	-	1.36	0.044	0.007	0.002	-
1,2-Dichloropropane	3.5	2.7	1.4	0.6	0.096	-	2.8	1.3	0.35	0.003	-
Benzene	36.3	29.2	7.2	4.34	0.71	0.23	29.2	8.43	2.33	0.04	-

Note: 1. Dosages in grams per 100 ml of solution

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 2A
EQUILIBRIUM CONCENTRATIONS OF EFFLUENT CONSTITUENTS IN ACTIVATED CARBON ISOTHERM STUDIES AT pH 7 (ppm)

		ICI (HDC) Carbon[1]					ICI (S-51) Carbon[1]				
Constituent	Untreated Effluent	0.1	0.5	1.0	5.0	10.5	0.1	0.5	1.0	5.0	10.5
TOC	1,418	1,223	800	454	30.2	19.1	1,130	856	378	35.8	17.4
Chlorobenzene	8.8	3.28	2.64	0.186	0.002	-	2.68	0.323	0.042	0.0004	-
p-Dichlorobenzene	36.0	0.9	0.032	0.003	-	-	0.238	0.041	0.003	-	-
Nitrobenzene	166	72.4	7.7	0.989	0.009	0.0009	35.3	7.95	1.08	0.006	0.0005
Phenol	30.8	28.2	17.8	3.34	0.038	0.0012	26.7	16.9	5.65	0.02	0.001
Dinitrotoluene	7.9	1.21	1.13	0.014	0.011	0.0006	0.829	0.856	0.007	0.002	0.0007
1,2-Dichloropropane	3.5	2.3	0.99	0.39	0.001	0.0005	2.5	1.0	0.24	0.003	—
Benzene	36.3	25.8	17.6	7.96	0.102	0.008	26.9	10.9	7.14	0.055	0.001

Note: 1. Dosages in grams per 100 ml of solution

EPA-287 (Cin.)
(4-76)

TABLE 3A
EQUILIBRIUM CONCENTRATIONS OF EFFLUENT CONSTITUENTS IN ACTIVATED CARBON ISOTHERM STUDIES AT pH 3 (ppm)

		ICI (HDC) Carbon[1]					ICI (S-51) Carbon[1]				
Constituent	Untreated Effluent	0.1	0.5	1.0	5.0	10.5	0.1	0.5	1.0	5.0	10.5
TOC	1,418	1,157	880	451	17	12	1,220	929	661	30	13
Chlorobenzene	8.8	1.03	0.176	0.035	0.002	-	3.42	0.587	0.017	0.0008	-
p-Dichlorobenzene	36.0	18	0.017	0.006	-	-	0.996	0.003	0.0006	-	-
Nitrobenzene	166	63.2	9.68	2.77	0.01	0.001	63.2	5.34	-	0.01	0.001
Phenol	30.8	26.8	22.8	12.3	0.015	0.002	24.9	14.5	-	0.012	0.002
Dinitrotoluene	7.9	1.13	0.041	0.009	0.006	0.0006	1.03	0.024	-	0.007	0.004
1,2-Dichloropropane	3.5	0.64	0.4	0.81	0.0004	<0.0001	2.0	0.92	0.2	0.003	-
Benzene	36.3	35	20	8.1	0.0039	0.0005	26	17.80	8.3	0.29	0.0025

Note: 1. Dosages in grams per 100 ml of solution

TABLE 4A
VIRGIN CARBON USED FOR 400° THERMAL REGENERATION STUDY

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.52	0	No Data	8.3	0	Negligible	No Data
A	1.56	0	No Data	5.2	0	0	No Data
A	2.34	0	No Data	26.2	0	1.7	No Data
A	3.12	0	No Data	22.1	0	1.1	No Data
A	3.90	0	No Data	33.9	0	8.7	No Data
A	4.42	35.5	No Data	26.4	0	7.8	No Data
A	4.94	92.3	No Data	27.4	0	10.8	No Data
A	5.33	127.8	No Data	26.5	0	2.9	No Data
A	5.72	142.0	No Data	27.3	0	12.9	No Data
A	5.98	220.1	2.7	33.9	21.2	21.4	No Data
A	6.11	272.6	No Data	36.0	24.6	22.0	No Data
A	6.24	305.3	No Data	34.8	141.1	21.6	No Data
B	14.95	56.8	No Data	33.7	0	25.3	No Data
B	17.29	191.7	No Data	32.8	0	29.3	No Data
B	17.81	234.3	No Data	28.2	0	28.5	No Data
B	18.07	248.5	No Data	36.0	0	30.6	No Data
B	18.33	284.0	No Data	31.4	0	30.8	No Data
C	13.00	No Data	No Data	No Data	0	0.5	3.0
C	15.73	No Data	No Data	36.0	0	9.5	No Data
C	19.63	35.5	No Data	23.8	0	18.0	No Data
C	21.58	28.4	No Data	36.0	0	22.8	No Data
C	24.70	No Data	No Data	34.9	0	27.9	No Data
C	26.26	No Data	No Data	36.0	0	30.8	No Data
C	29.38	No Data	No Data	32.3	No Data	30.8	No Data

Notes: 1. No data indicates that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 5A
THERMAL REGENERATION, FIRST REGENERATION (400°C)

Sampling point	Volume through column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	35.5	0.3	16.8	20.6	7.0	0
A	0.39	56.8	0.2	13.4	13.8	3.3	0
A	0.65	71.0	0.3	17.4	19.8	6.2	0
A	0.91	205.9	0.3	19.9	13.2	9.1	0
A	1.04	241.4	0.4	21.5	30.4	10.9	0
A	1.30	284.0	0.7	22.1	23.1	12.2	0
B	0.39	0	0.01	5.9	3.2	0	0
B	0.91	0	0	0	3.5	0	0
B	1.43	0	0.1	15.7	6.6	1.8	0
B	1.95	7.1	0.3	19.1	11.0	5.2	0
B	2.47	49.7	0.4	24.0	-	9.6	0
B	2.99	113.6	0.4	17.5	17.6	12.3	0
B	3.77	106.5	0.3	23.3	14.9	15.7	6.1
B	5.07	156.2	0.1	17.2	21.4	18.9	0
B	5.59	184.6	0.5	22.5	18.1	18.9	7.0
C	0.78	0	0	0	2.3	0	0
C	6.50	0	0.1	28.1	13.4	0	0
C	8.32	49.7	0.3	29.2	7.6	6.9	6.3
C	11.18	120.7	0.9	22.4	16.8	15.1	6.1
C	12.22	163.3	0.3	22.4	17.6	16.7	6.5
C	13.00	170.4	0.7	23.8	19.6	18.3	6.5

Note: 1. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TABLE 6A
THERMAL REGENERATION, FIRST REGENERATION (400°C)

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.39	49.7	0.5	17.8	15.8	8.7	6.1
A	0.65	92.3	2.0	28.1	10.3	9.2	7.9
A	1.04	149.1	3.1	35.5	16.6	13.0	7.9
A	1.17	213.0	4.2	31.9	17.6	12.8	7.9
A	1.30	262.7	4.2	36.0	28.6	15.6	7.9
A	1.43	326.6	6.4	36.0	30.2	15.6	7.9
B	1.77	0	0	14.2	8.6	0	5.4
B	1.95	0	0	20.4	11.6	4.5	5.7
B	3.25	0	0.3	20.0	14.3	13.3	5.9
B	4.29	71.0	0.2	20.8	14.4	15.5	7.9
B	5.85	127.8	0.1	21.6	17.3	17.6	6.5
B	6.37	142.0	0.2	21.2	11.6	18.4	7.9
B	6.63	213.0	0.4	20.8	22.6	18.9	6.1
B	6.89	326.6	0.4	20.7	22.6	19.8	7.9
C	0.65	0	0	0	No Data	0.6	7.9
C	1.82	0	0	0	No Data	0.4	7.9
C	3.38	0	0	0.6	No Data	0.4	7.9
C	5.46	0	0.9	36.0	No Data	1.8	7.9
C	7.15	0	2.0	36.0	No Data	12.4	7.9
C	7.93	49.7	1.4	36.0	No Data	17.2	7.9
C	8.32	71.0	1.4	36.0	No Data	16.2	7.9
C	8.71	92.3	2.0	36.0	No Data	19.6	7.9

Notes: 1. No data indicates that analytical interferences on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 7A
THERMAL REGENERATION, THIRD REGENERATION (400°C)

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.52	28.4	2.0	19.8	19.4	4.6	4.4
A	0.91	113.6	3.7	35.6	30.2	10.8	5.3
A	1.17	194.5	5.3	35.6	30.2	14.2	4.4
A	1.30	248.5	5.3	36.0	30.2	16.3	5.1
A	1.43	298.2	7.5	34.4	59.8	15.2	5.9
B	0.78	-	0.3	7.9	5.6	1.2	6.2
B	1.82	35.5	0.3	33.2	13.3	6.7	4.9
B	2.86	56.8	0.3	36.0	35.0	13.1	5.3
B	3.90	92.3	0.3	36.0	40.0	17.6	4.8
B	4.68	142.0	2.0	36.0	54.8	18.0	4.8
B	5.20	213.0	2.0	36.0	49.8	21.0	5.6
B	5.46	265.5	3.1	36.0	59.8	19.7	5.2
B	5.72	319.5	3.1	36.0	59.8	20.8	5.1
C	1.95	-	0	0.8	No Data	1.1	0
C	3.90	-	2.0	36.0	No Data	5.9	0
C	5.85	28.4	1.4	36.0	No Data	12.1	3.3
C	7.41	42.6	4.2	36.0	No Data	17.0	3.3
C	8.97	71.0	3.7	36.0	No Data	20.0	3.1
C	10.53	106.5	4.2	36.0	No Data	21.7	3.3
C	10.92	127.8	3.04	36.0	No Data	21.0	3.2
C	11.31	170.4	4.2	36.0	No Data	21.5	3.2

Notes: 1. No data indicates that analytical interferences on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 8A
THERMAL REGENERATION, FOURTH REGENERATION (400°C)

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm) TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.52	56.8	3.1	26.2	20.3	7.4	5.2
A	0.65	117.9	4.2	23.5	27.7	10.0	5.7
A	0.78	139.1	4.2	36.0	35.0	12.5	4.8
A	0.91	298.2	8.8	28.1	59.8	13.4	5.2
B	0.52	-	0.9	3.3	5.1	1.1	5.6
B	1.56	35.5	5.3	15.3	9.1	8.1	5.2
B	2.60	99.4	5.9	22.4	15.4	15.3	5.7
B	3.38	174.7	4.8	36.0	40.0	17.8	5.4
B	3.64	213.0	8.1	34.6	37.5	19.5	5.4
B	3.90	284.0	8.8	26.2	40.0	21.0	5.7
C	1.95	-	4.2	15.4	No Data	4.2	5.4
C	4.24	21.3	8.8	22.4	No Data	14.4	6.7
C	6.24	56.8	5.3	36.0	No Data	18.9	6.9
C	7.80	92.3	3.7	36.0	No Data	18.9	7.9
C	8.97	134.9	4.2	36.0	No Data	21.5	7.3
C	9.75	213.0	4.8	36.0	No Data	21.9	5.7
C	10.14	298.2	6.4	36.0	No Data	22.5	5.7

Notes:
1. No data indicates that analytical interferences on the instrument precluded quantification.
2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8''

EPA-287 (Cin.)
(4-76)

TABLE 9A
VIRGIN CARBON USED FOR 800°C THERMAL REGENERATION STUDY

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm) TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	No Data	0	0	0	0	0.5
A	1.95	No Data	0	0	0	0	No Data
A	3.12	No Data	0	14.8	0	0	0.6
A	3.90	21.3	1.0	36.0	0	0.8	0.7
A	4.68	42.6	0.1	36.0	0	2.6	0.7
A	5.46	42.6	0.7	36.0	0	5.5	1.2
A	6.24	56.8	1.4	36.0	0	9.3	1.4
A	6.76	85.2	0.8	36.0	0	11.2	1.0
A	7.15	113.6	0.5	36.0	0	13.3	1.0
A	7.41	127.8	0.3	36.0	0	11.2	1.0
A	7.67	170.4	0.8	36.0	0	13.0	0.7
A	7.93	220.1	0.7	36.0	0	13.2	1.0
A	8.06	262.7	0.7	36.0	0	14.4	1.0
A	8.19	284.0	0.7	36.0	1.2	13.8	0.7

Notes: 1. No data indicates that analytical interferences on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

EPA-287 (Cin.)
(4-76)

TABLE 10A
THERMAL REGENERATION AT 800°C, FIRST REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	0	0.7	1.6	0	0.2	0
A	1.30	14.2	0.6	21.0	0	3.6	0
A	1.95	28.4	0.7	32.6	0	7.0	3.1
A	2.60	42.6	0.7	36.0	0	14.6	3.2
A	3.25	78.1	1.0	36.0	0	17.3	3.2
A	3.51	113.6	0.3	36.0	0	18.1	3.2
A	3.90	142.0	0	36.0	0	19.1	3.2
A	4.16	163.3	0.1	36.0	0	18.9	2.2
A	4.42	205.9	0	36.0	0	19.8	2.7
A	4.68	248.5	0.4	36.0	0	19.8	2.2
A	4.81	284.0	0	36.0	0	20.2	3.2
A	4.94	284.0	0.4	36.0	0	21.0	3.2

Note: TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 11A
VIRGIN CARBON USED FOR STEAM REGENERATION STUDY

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	0	0	0	0	0	0
A	1.56	0	0	0	0	0	0.6
A	3.12	0	0	14.4	1.2	1.8	2.9
A	4.68	0	0.7	36.0	No Data	6.1	2.7
A	5.[illegible]	49.7	0	36.0	No Data	12.7	3.4
A	6.24	85.2	0.7	36.0	No Data	12.2	3.1
A	6.76	134.9	1.5	36.0	No Data	15.0	3.4
A	7.15	142.0	0.7	36.0	No Data	15.0	3.1
A	7.41	156.2	2.3	36.0	No Data	15.4	2.9
A	7.67	177.5	0.7	36.0	No Data	15.7	4.1
A	7.93	191.7	1.2	36.0	No Data	19.9	3.6
A	8.06	213.0	1.0	36.0	50.6	18.6	3.6
A	8.19	284.0	0.4	36.0	64.7	18.4	2.2
B	3.12	0	0	0	0.8	1.1	1.9
B	5.20	0	0	0	0	0.9	2.1
B	7.80	0	0	36.0	No Data	1.4	2.2
B	10.80	0	0.5	36.0	No Data	4.8	2.2
B	13.00	0	0.7	36.0	2.0	10.1	2.7
B	15.60	49.7	0.1	36.0	12.8	17.3	1.9
B	16.90	85.2	0.7	36.0	17.1	19.2	2.2
B	17.68	99.4	0.1	36.0	20.2	21.2	1.9
B	18.46	109.3	0.1	36.0	24.6	21.0	1.9

(Continued)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 11A (Continued)

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm) TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
B	19.24	142.0	0.1	36.0	32.5	21.6	2.2
B	20.02	198.8	0.1	36.0	41.3	23.9	2.2
B	20.54	198.8	0.1	36.0	46.3	22.6	2.2
B	20.80	298.2	1.2	36.0	45.7	22.8	2.2
C	5.85	0	0	0	0	0.2	1.7
C	9.25	0	0	0	0.5	1.0	No Data
C	13.65	0	0.3	36.0	1.2	1.9	3.6
C	17.55	0	0.3	36.0	16.3	8.2	3.1
C	21.45	14.2	0.7	36.0	23.2	16.5	2.7
C	23.40	71.0	0.4	36.0	26.9	18.8	2.2
C	25.35	99.4	No Data	36.0	No Data	20.8	5.1
C	26.52	120.7	0.7	36.0	No Data	20.5	3.1
C	28.08	163.3	0.1	27.8	No Data	19.9	3.4
C	28.86	213.0	1.0	22.2	No Data	20.9	3.1
C	29.25	312.4	0.7	35.8	No Data	22.6	3.1

Notes:
1. No data indicates that analytical interference on the instrument precluded quantification.
2. TOC concentrations based on ultraviolet absorption.

TABLE 12A
STEAM REGENERATION, FIRST REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm) TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	0	0	3.6	0	1.8	No Data
A	0.78	0	0	17.0	0.8	4.0	3.3
A	1.30	7.1	0	22.2	6.0	6.7	3.1
A	1.69	5.2	0	27.8	9.6	9.9	3.1
A	2.08	149.1	0.1	36.0	15.3	13.1	3.6
A	2.34	255.6	0.1	30.2	17.6	13.1	3.4
A	2.47	312.4	No Data	28.6	21.9	13.7	2.7
B	0.52	0	0	0	0	1.9	2.7
B	1.56	0	0	2.6	1.5	3.1	2.7
B	2.60	0	0	16.2	0	2.9	3.0
B	4.16	0	0	36.0	2.3	5.3	No Data
B	5.46	35.5	0	36.0	0.3	8.6	No Data
B	6.50	71.0	0.1	36.0	0.3	10.8	No Data
B	7.54	92.3	0	36.0	1.7	11.2	No Data
B	8.06	115.0	0.1	36.0	9.6	13.5	No Data
B	8.58	163.3	0.1	36.0	10.6	9.9	No Data
B	9.10	255.6	0.1	36.0	14.4	14.2	4.6
B	9.36	312.4	0.1	36.0	11.0	16.1	3.9
C	0.78	0	0	0	0	0	0
C	3.51	0	0	0	0	0.1	0
C	6.63	0	0	36.0	0	0	0
C	8.19	0	0	36.0	1.7	2.1	2.2
C	10.92	42.6	0.1	36.0	8.8	8.7	2.7
C	12.87	85.2	0.1	27.8	11.0	10.6	2.2
C	14.43	110.8	0.4	24.6	12.3	12.0	2.4
C	15.34	177.5	0.7	31.8	13.6	16.5	2.7
C	15.94	255.6	0	27.4	13.6	15.0	2.4
C	16.38	312.4	0.1	36.0	17.1	15.4	2.7

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 13A
STEAM REGENERATION, SECOND REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.26	0	0.1	14.6	2.2	2.3	1.7
A	0.65	63.9	0.1	23.0	7.0	5.5	2.4
A	0.91	132.1	0.1	28.6	13.6	8.9	2.4
A	1.04	174.7	0.3	31.0	17.9	0.5	2.4
A	1.17	234.3	0.7	36.0	19.8	12.9	2.7
A	1.30	305.3	0.7	33.4	26.9	12.0	2.4
B	0.52	0	0	6.6	0	0	2.2
B	1.30	0	0	21.8	0.8	1.4	2.3
B	2.08	0	0.1	25.4	4.8	5.1	2.8
B	2.86	21.3	0.1	36.0	10.5	9.5	No Data
B	3.38	71.0	0.1	36.0	11.0	11.8	2.4
B	4.16	92.3	0.4	36.0	8.8	13.1	2.2
B	4.68	136.3	0.4	31.8	12.8	12.0	2.2
B	5.20	205.9	0.4	29.4	11.0	14.4	1.7
B	5.46	284.0	0.7	36.0	14.4	16.5	1.9
C	0.78	0	0	0	0	0	0
C	2.34	0	0	1.4	0	0	0
C	3.90	0	0.1	30.6	0	0.5	1.4
C	5.46	0	1.5	36.0	0	3.3	2.4
C	7.02	14.2	0.7	36.0	1.2	7.2	2.2
C	8.88	63.9	0.7	36.0	0.8	11.2	2.2
C	9.75	85.2	0.4	32.6	1.7	12.6	1.9
C	10.92	113.6	0.4	36.0	5.6	15.0	2.2
C	11.70	163.3	0.4	36.0	5.6	15.0	2.4
C	12.09	205.9	0.7	36.0	6.5	15.9	1.9
C	12.48	284.0	0.4	35.0	5.1	15.3	1.9

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

TABLE 14A
STEAM REGENERATION, THIRD REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.13	28.4	0	11.0	0	2.1	1.9
A	0.39	71.0	0.1	25.8	0	5.2	2.2
A	0.91	191.7	0.7	28.6	8.3	10.6	2.2
A	1.17	269.8	2.6	36.0	17.1	13.6	2.2
A	1.30	298.2	1.0	36.0	18.9	15.2	1.9
B	0.52	No Data	0.1	17.8	0	1.3	1.4
B	1.04	28.4	0	27.4	0	2.1	1.9
B	1.82	56.8	0.1	36.0	1.3	7.2	1.7
B	2.60	No Data	0.4	36.0	2.8	8.9	No Data
B	3.38	113.6	0.7	36.0	1.7	14.1	1.9
B	4.16	159.0	0.4	36.0	8.3	15.3	1.9
B	4.68	241.4	0.4	36.0	12.1	17.8	1.7
B	4.94	284.0	0.4	36.0	14.9	16.7	1.7
C	0.78	0	0	0	0	0	1.0
C	3.12	0	0	19.4	0	0.2	1.4
C	5.46	28.4	0.3	30.2	0	3.7	1.7
C	7.80	49.7	0.1	36.0	3.0	12.0	1.7
C	8.97	71.0	0.4	36.0	3.0	12.0	1.7
C	10.14	99.4	0.3	36.0	2.2	16.3	1.7
C	11.30	142.0	0.1	36.0	3.0	17.8	1.4
C	12.09	213.0	0.1	36.0	3.0	19.1	1.7
C	12.48	284.0	0.5	36.0	3.0	17.9	1.9

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

EPA-287 (Cin.)
(4-76)

TABLE 15A
STEAM REGENERATION, FOURTH REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.13	18.5	0	8.4	0	2.0	1.4
A	0.39	42.6	0	14.6	1.7	3.1	1.4
A	0.65	78.1	0.1	21.8	8.3	5.4	1.4
A	0.91	142.0	0.6	28.6	15.3	8.0	1.7
A	1.17	149.1	1.0	27.0	21.6	9.4	1.2
A	1.30	312.4	2.0	36.0	51.1	12.4	1.4
B	0.52	No Data	0	5.8	0	0	1.2
B	1.04	35.5	0.1	23.5	0	3.4	1.4
B	1.82	66.7	0.6	34.2	0.3	8.4	1.2
B	2.60	106.5	0.7	36.0	3.8	12.6	1.2
B	3.38	177.5	0.5	36.0	11.4	14.6	1.2
B	3.90	248.5	0.8	36.0	15.4	16.5	1.4
B	4.16	284.0	1.2	34.8	19.8	14.7	1.4
C	0.78	No Data	0	0	0	0	1.2
C	2.34	No Data	0	15.8	0	0.1	1.4
C	3.90	28.4	0.3	36.0	0	2.7	1.4
C	5.46	38.3	0.1	36.0	0	8.7	1.2
C	7.02	63.9	0.3	36.0	0	12.4	1.7
C	8.19	78.1	0.8	36.0	0	16.1	1.2
C	9.75	170.4	0.7	36.0	1.2	15.8	1.4
C	10.53	262.7	0.8	36.0	2.5	16.3	1.2
C	10.92	312.4	0.4	36.0	4.8	18.3	1.2

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 16A
STEAM REGENERATION, FIFTH REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.13	49.7	0.1	15.0	3.5	3.8	1.0
A	0.39	85.2	0.5	16.4	13.6	4.6	1.0
A	0.65	227.2	1.2	27.0	35.0	8.1	1.2
A	0.78	298.2	1.4	27.8	35.5	9.3	1.4
B	0.26	No Data	0	9.2	0	0.5	0
B	1.30	42.6	0.3	28.6	0	5.5	0.7
B	1.82	82.4	0.5	31.4	2.2	0.3	1.0
B	2.34	164.7	1.2	32.4	10.6	11.6	1.0
B	2.60	213.0	1.0	36.0	12.8	12.8	1.0
B	2.86	284.0	0.8	31.0	11.8	11.6	1.0
C	0.78	No Data	0	0.3	0	0	0
C	1.95	No Data	0.6	16.4	0	0.7	0.7
C	3.12	14.2	0.5	29.4	0	2.3	0.7
C	5.07	42.6	0.5	36.0	0	9.5	1.2
C	6.24	92.3	1.4	36.0	0	14.4	1.4
C	7.02	134.9	0.1	36.0	0.8	14.4	1.2
C	7.80	227.2	0.5	36.0	2.2	16.1	1.2
C	8.19	319.5	0.8	27.4	2.5	13.3	1.2

Notes:
1. No data indicated that analytical interference on the instrument precluded quantification.
2. TOC concentration based on ultraviolet absorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 17A
EQUILIBRIUM CONCENTRATION OF EFFLUENT CONSTITUENTS IN XAD-4 RESIN ISOTHERM STUDIES (ppm)

Constituent	Average Untreated Effluent Concentration	XAD Dosage (g) per 100 ml of solution									
		pH 9					pH 6				
		0.2	0.5	1.0	5.0	10.5	0.2	0.5	1.0	5.0	10.5
TOC	1,418	905	620	390	177	92	890	577	349	191	68
Chlorobenzene	8.8	1.77	0.36	0.082	-	-	1.87	0.27	0.076	-	-
p-Dichlorobenzene	36.0	30.8	25.6	17.6	1.78	0.151	31.8	27.8	16.6	1.38	
Nitrobenzene	166	61.1	32.3	15.1	3.04	1.64	86.7	31.9	16.2	3.52	1.94
Phenol	30.8	28.0	22.6	17.0	3.85	1.1	28.4	22.0	16.9	2.32	0.91
Dinitrotoluene	7.9	3.63	2.98	2.98	-	-	3.51	3.21	2.85	-	-

Note: 1. TOC values are estimated from ultraviolet absorption results.

2. Average value from Table 2

EPA-287 (Cin.)
(4-76)

TABLE 18A
VIRGIN XAD-4 RESIN USED FOR REGENERATION STUDY

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	21.3	0	0	0	0	0.7
A	0.78	32.7	0	0	0	0	1.0
A	1.56	35.5	0	0	0	0	0
A	2.145	44.0	0	0	0	0	1.0
A	2.925	61.1	0	0	0	0	1.0
A	3.51	71.0	0	0	0	0	No Data
A	4.095	107.9	0	0.1	0	0.1	1.2
A	4.485	177.5	0	1.6	0	1.0	1.2
A	4.68	213.0	0	3.0	0	1.8	1.2
A	4.875	305.3	0.1	4.0	No Data	2.6	1.0

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

9-1/8
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 19A
XAD-4 REGENERATION, FIRST REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	0	0	0	0	0	0.7
A	0.780	18.5	0	0	0	0	0.8
A	1.560	35.5	0	0	0	0	1.1
A	2.145	42.6	0	0	0	0	1.1
A	2.730	46.9	0	0	0	0	1.0
A	3.510	49.7	0	0	0	0	1.0
A	4.290	59.6	0	0	0	0	0.7
A	5.070	80.9	0	0	0	0	0.7
A	5.460	119.3	0	0.7	0	0	1.0
A	5.655	180.3	0.1	0.3	0	0	1.0
A	5.850	284.0	0	3.2	0	0	1.1

Note: TOC concentration basd on ultraviolet absorption.

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 20A
XAD-4 REGENERATION, SECOND REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	7.1	0	0	0	0	No Data
A	0.780	24.1	0	0	0	0	0.7
A	1.365	32.7	0	0	0	0	0.7
A	1.950	42.6	0	0	0	0	0.7
A	2.535	42.6	0	0	0	0	0.7
A	3.510	45.4	0	0	0	0	No Data
A	4.045	55.4	0	0	0	0	0.7
A	4.680	59.6	0	0	0	0	1.0
A	5.265	63.9	0	0	0	0	1.7
A	5.850	66.7	0	0	0	0	0.8
A	6.240	82.4	0	0	0	0	0.7
A	6.630	102.2	0	0	0	0	0.8
A	7.020	132.1	0	0.8	0	0	0.8
A	7.300	298.2	Negligible	7.6	0	1.3	0.8

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

TABLE 21A
XAD-4 REGENERATION, THIRD REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	0	0	0	0	0	0
A	0.780	11.4	0	0	0	0	0
A	1.365	28.4	0	0	0	0	0
A	1.950	38.3	0	0	0	0	0.5
A	3.705	49.7	0	0	0	0	0.6
A	5.460	62.5	0	0	0	0	0.7
A	6.435	113.6	0	0	0	0	0.5
A	6.825	180.3	0	2.8	0	0	0.6
A	7.020	244.2	0.3	6.5	0	0.4	0.6
A	7.215	305.3	Negligible	14.8	0	1.3	0.7

Note: TOC concentration basd on ultraviolet absorption.

TABLE 22A
XAD-4 REGENERATION, FOURTH REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	0	0	0	0	0	0
A	0.780	18.5	0	0	0	0	0
A	2.535	42.6	0	0	0	0	No Data
A	4.290	56.8	0	0	0	0	0.6
A	5.655	88.0	0	0	0	0	No Data
A	6.045	123.5	0	1.0	0	0	No Data
A	6.435	224.4	0	5.0	0	0.3	0.7
A	6.630	312.4	0	8.5	0	0.8	0.7

Notes: 1. No data indicated that analytical interference on the instrument precluded quantification.

2. TOC concentration based on ultraviolet absorption.

TABLE 23A
XAD-4 REGENERATION, FIFTH REGENERATION

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.195	14.2	0	0	0	0	0
A	1.365	39.8	0	0	0	0	0.5
A	3.12	56.8	0	0	0	0	1.2
A	4.095	106.5	0	0.1	0	0	0.8
A	4.985	221.5	0	0	3.8	0	0.2
A	4.68	284.0	0	6.2	0	0.6	0.7

Notes: TOC concentration based on ultraviolet absorption.

TABLE 24A
INITIAL TEST RUN AFTER 3 TIMES NORMAL SOLVENT PREPARATION WASH

Sampling Point	Volume Through Column (liters)	Effluent Concentration (ppm)					
		TOC	Chlorobenzene	p-Dichlorobenzene	Nitrobenzene	Phenol	Dinitrotoluene
A	0.975	0	0	0	0	<0.3	0
A	1.950	0	0	0	0	<0.3	0
A	2.925	0	0	0	0	<0.3	0
A	3.900	0	0	0	0	0	0
A	4.875	17.0	<0.9	<3.6	<1.7	<0.3	0
A	5.655	136.3	0	<3.6	0	<0.3	0
A	5.850	213.0	0	2.0	0	<0.3	1.4
A	6.045	312.4	<0.9	4.6	0	1.4	1.4

Notes: TOC concentration basd on ultraviolet absorption.

GLOSSARY

adsorbent: A substance which has the ability to condense or hold molecules of other substances on its surface.

adsorption: Adherence of the atoms, ions or molecules of a gas or liquid to the surface of another substance, called the adsorbent.

adsorption isotherm: A measurement of the adsorptive capacity of an adsorbent as a function of the concentration, or pressure, of the adsorbate at a given temperature. It is the constant temperature relationship between amount adsorbed per unit weight of adsorbent and the equilibrium concentration, or partial pressure.

6-1/2"

bed volume: That volume of water which would occupy, on a superficial basis, the gross volume of the adsorbent bed, i.e. bed height multiplied by bed cross section.

9-1/8"

breakthrough: The point in time when the concentration of a specific compound in an adsorption effluent exceeds a given level.

hydrophobic: Excluding water at active surface sites, preferentially adsorbing non-aqeous, organic compounds.

macroreticular: Porous, with complex internal channels and surfaces of high effective active area.

regeneration: Treatment, such as by heat treatment or by washing with a solvent or chemically active solution, in order to restore activity of an adsorbent.

resin: A macroreticular polymeric material formed in beads of high effective surface area and activity.

van der Waals forces: Intermolecular attraction, relatively weak but effective in non-polar adsorption.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)